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**TECHNOLOGICAL**  
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**A PRODUCT CONCEPTUALIZATION STRATEGY  
BASED ON CROWD-INNOVATION**

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## Summary

Product conceptualization plays a critical role in new product development. Research has shown that 75–80% of a product’s lifecycle cost is determined during the conceptual design phase. Thus, achieving a competitive edge at the front end could lead to more opportunities for successful final products. However, to realize product innovation in the conceptual design stage is challenging. The incomplete and fuzzy nature of this phase causes difficulties in creating a reliable innovation environment. To tackle this problem, a possible solution from the resource-based view (RBV) is to involve external resources and obtain contributions from multiple facets. In this regard, various design strategies, such as open innovation and value co-creation, have been proposed, through which the potential of utilizing the dispersed knowledge distributed among the crowd for creativity is deeply recognized. Hence, crowd wisdom could be a heterogeneous organizational knowledge resource that deserves further research. Therefore, this study seeks to contribute to the utilization of crowdsourcing in product conceptualization for fostering innovative designs and for advancing the research in this field.

The integration of crowdsourcing in product conceptualization is a complex task. Firstly, crowdsourcing currently offers only a basic conceptual scheme to connect assigners and contributors and lacks systematic management to obtain effective entries with guaranteed quality. Secondly, product conceptualization consists of a series of consecutive activities, i.e., concept generation, concept evaluation, and selection. Therefore, the integration of crowdsourcing should simultaneously

consider each design process. Thirdly, crowdsourcing responses are often in large numbers and in various formats, which leads to further difficulties in dealing with crowdsourced conceptual designs. Specific issues, such as how to incorporate crowdsourcing to facilitate concept generation for the creation of innovative concepts, how to implement concept evaluation and selection in a crowdsourcing environment, and how to verify crowdsourced conceptual designs further in terms of innovativeness, have to be addressed well.

In this work, a product conceptualization strategy based on crowd-innovation (PCSCI) is proposed consisting of three sub-systems: web-based knowledge acquisition platform (WKAP), artificial intelligence-based innovative concept discovery platform (AI-ICDP), and concept learning and retention platform (CLRP). Specifically, the WKAP stimulates concept generation and consolidates the collected concepts into a well-organized knowledge base. For this purpose, a crowdsourcing platform development approach is established with careful consideration regarding target analysis, task design, and cheating control. The AI-ICDP selectively extracts concept knowledge from the knowledge base and identifies promising design concepts. In this sub-system, a text mining process is deployed for knowledge extraction, a concept reconstruction strategy is proposed for unifying concept formats, and a concept clustering process is employed for simplifying concept comparison and selection. The third sub-system, i.e., CLRP, examines the competitive edges of the concept candidates selected by the AI-ICDP in terms of innovativeness and retains the concepts with better performance. An enhanced innovation evaluation method based on grey and fuzzy theories is developed. For each sub-system, a numerical illustration based on a future personal

computer (PC) design project is presented. The results demonstrate that the proposed PCSCI has advantages in gaining more effective contributions (by WKAP), identifying promising concept candidates more efficiently (by AI-ICDP), and achieving a more scientific and rational measurement of innovativeness (by CLRP). In conclusion, this research creates a collective intelligence environment for product conceptualization, advances the applications of computational intelligence in the conceptual design stage, and lays the foundation for further exploration in related areas.

## List of Publications

**Chang, D.**, and Chen, C.-H. (2015). Product concept evaluation and selection using data mining and domain ontology in a crowdsourcing environment. *Advanced Engineering Informatics*. 29(4), 759-774.

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**Chang, D.**, and Chen, C.-H. (2014). Exploration of a Concept Screening Method in A Crowdsourcing Environment. In *Proceedings of the 21st ISPE International Conference on Concurrent Engineering*. 861-870, Beijing, China, September 8-10, 2014. (*The Best Paper Award of CE2014*)

**Chang, D.**, and Chen, C.-H. (2014). Integration of Knowledge Engineering and 3D Printing for Digital Design and Manufacturing – A Case Study. In *Proceedings of the 1st International Conference on Progress in Additive Manufacturing*. 47-52, Singapore, May 26-28, 2014.

**Chang, D.**, and Chen, C.-H. (2013). Understanding the Customer Involvement in Radical Innovation. In *Proceedings of the 20th International Conference on Concurrent Engineering*. 72-80, Melbourne, Australia, September 2-5, 2013.

**Chang, D.**, and Lee, K.M. (2012). Enhancing Workplace Safety with TRIZ. In *Proceedings of the 6th International Conference on Management of Innovation and Technology*. 652-657, Sanur Bali, Indonesia, June 11-13, 2012.

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## List of Abbreviations

AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AI-ICDP	Artificial Intelligence-based Innovative Concept Discovery Platform
ANN	Artificial Neural Network
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CDH	Concept Development Hierarchy
CLRP	Concept Learning and Retention Platform
COG	Center of Gravity
DoIF	Degree of Innovation Freedom
FM	Functional Mechanisms
GF-CIEA	Grey-and-Fuzzy-based Concept Innovativeness Estimation Approach
HCI	Human Computer Interaction
HIT	Human Intelligence Task
ICPD	Innovativeness of Conceptual Product Design
MADM	Multi-Attribute Decision Making
NPD	New Product Development
ODQ	Overall Design Quality
OM	Operation Mode

PCSCI	Product Conceptualization Strategy based on Crowd-Innovation
PD	Participatory Design
PDD	Product Design and Development
PE	Participatory Ergonomics
ProCES	Product Concept Evaluation and Selection
QFD	Quality Function Deployment
RBV	Resource-based View
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TRIZ	Theory of Inventive Problem Solving
UI	User Interface
VR	Virtual Reality
WKAP	Web-based Knowledge Acquisition Platform

# Chapter 1 Introduction

This Chapter comprises four sections. The research background is presented in Section 1.1, where the importance of product innovation is illustrated, and the power of crowd wisdom is anticipated. Based on the research background, the objective of the study is stated in Section 1.2, followed by the definition of the research scope. Subsequently, the significance of the work is elucidated in Section 1.3. The introductory chapter concludes with an outline of the organization of this thesis in Section 1.4.

## 1.1 Background

Product design can be perceived as the constructive process of creating a new product. It is systematically executed through a series of design activities such as the perception of a market opportunity, the conception of the attributes of artifacts, and the testing of conceptual designs (Ulrich and Eppinger, 2012). According to Pahl and Beitz (1996), a well-organized design process is significant in increasing the success rate of a new venture. This belief has driven the growth of an important branch of design science over the past few decades, which advocates certain prescriptive approaches towards design (Al-Salka et al. 1998). In this field of study, a range of design methodologies, design systems, and models has been proposed, wherein product conceptualization—the front end of the design process—has attracted much research attention. According to Huang et al. (2006), compared to the detailed design stage, there is greater emphasis laid on creativity in the conceptual design stage.

In fact, industries have acknowledged that conceptual design has a pivotal position in the design process. Tables 1.1 and 1.2 and Figure 1.1 are presented to illustrate the fact that the conceptual design stage has huge potential for the significant improvements in development time and overall quality with a relatively low change cost. Even a detailed design with the highest standard cannot compensate for a poor design that was formulated at the start. Because of the importance of the design phase, considerable attention has been devoted to product conceptualization in order to achieve competitive designs at the initial design phase.

Table 1.1 The typical cost for each change made during the development of a major electronics product<sup>1</sup>

When design changes are made	Cost \$
During Design	1,000
During Design Testing	10,000
During Process Planning	100,000
During Test Production	1,000,000
During Final Production	10,000,000

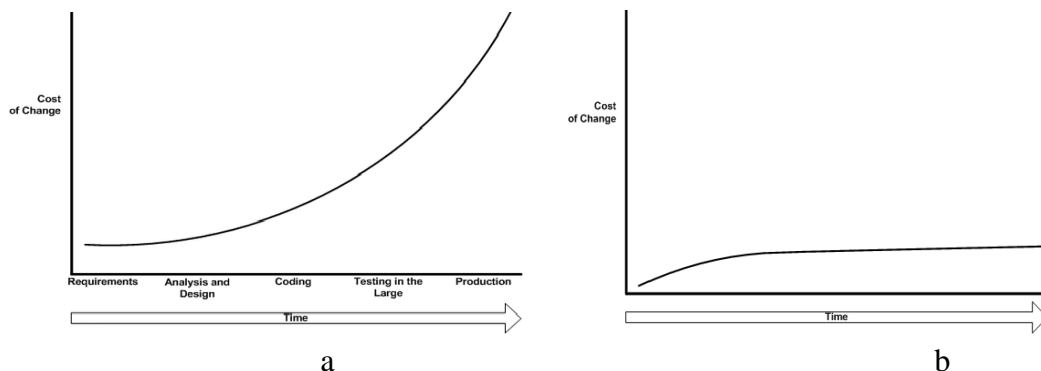


Figure 1.1 Cost of change curve: a. Traditional exponential cost curve (Boehm, 1981) b. Agile system change cost curve (Beck, 2002)

<sup>1</sup> Data: DATAQUEST, INC.

Table 1.2 Benefits from designing manufacturability, quality, and ease of maintenance into the product at the start<sup>2</sup>

<b>Benefits from designing manufacturability, quality, and ease of maintenance into the product at the start</b>	<b>Percent</b>
Development Time	30-70% Less
Engineering Changes	65-90% Fewer
Time to Market	20-90% Less
Overall Quality	200-600% Higher
White-Collar Productivity	20-110% Higher
Dollar Sales	5-50% Higher
Return on Assets	20-120% Higher

With the rapid growth in competition intensity, continuous product improvement is imperative for producing competitive products. In a dynamic and constantly changing market environment, enterprises without the adaptability required to overcome outside challenges would eventually fail in the face of competition. Hence, product innovation, which advocates the search for solutions for product improvements through the creation and introduction of a good that is either new or improved compared to previous goods, is of great importance. Companies such as Apple and Proctor & Gamble (P&G) have devoted considerable effort to product innovation in order to retain their leading position. Inspired by this phenomenon, there is an increase in the awareness about the need to reach product innovation in the initial product conceptualization phase. Hayes et al. (1988) claimed that an important aspect of a successful product development project was bringing conflicts to the early stage of the development process; they pointed out the importance of “predevelopment activities” (i.e., design activities at the very

<sup>2</sup> Data: National Institute of Standards and Technology, Thomas group Inc., Institute for Defense Analysis

beginning) in the development of successful final products. Further, they recognized the imperativeness of achieving creative conceptual designs.

However, to realize product innovation in the conceptual design stage is challenging from a practical perspective. Prior product innovation studies mainly focused on improving specific physical attributes of artifacts during the detailed design stage (e.g., selection of recyclable materials, optimization of partial mechanism, and application of breakthrough technologies). This is because the design information for this stage is relatively complete and well-defined; therefore, the available innovation resources included various aspects (e.g., product feature reconfiguration, manufacturing process, cost-benefit analysis) (Simth et al. 2012; Lambertini and Mantovani, 2009; Norbäck and Persson, 2012). For the product conceptualization phase, the design information is incomplete and ambiguous. The fuzzy nature of this phase leads to difficulties in creating a reliable innovation environment. To tackle this problem, a possible solution that is grounded in the resource-based view (RBV) is to involve external resources and gain contributions from multiple entities (e.g., consumers, suppliers). In modern industries, vast amounts of knowledge are exchanged concurrently, with the participation of different stakeholders (Yan et al., 2009b). Thus, various design strategies such as open innovation (Herzog, 2011) and value co-creation (O'Cass and Sok, 2012; Van Horne et al., 2006) have been proposed. According to Bücheler and Sieg (2011), the intense interactions between groups and individuals during idea generation, formulation of hypotheses, evaluation, and data analysis have been a trend in modern research. Based on this insight, dispersed knowledge from individuals has been given more attention in recent years. Greengard (2011) stated that virtually

everyone has the potential to plug in valuable information. Therefore, the dispersed knowledge from distributed individuals is studied as a heterogeneous organizational knowledge resource (Prpić and Shukla, 2013).

A look at the current practices of utilizing individuals' knowledge reveals that crowdsourcing, which draws upon the expertise distributed among the crowd and relies on Web2.0 to realize intense interactions (Afuah and Tucci, 2012; Geiger et al., 2011), has become a phenomenon driven by practitioners (Hammon and Hippner, 2012; Brabham, 2008; Rossen and Lok, 2012). iStockPhoto.com and Threadless.com are good examples of crowdsourcing-based enterprises that have achieved a creative business model (Hammon and Hippner, 2012). The systematic integration of crowdsourcing in product conceptualization is advocated (Simula and Ahola, 2014). Kleeman et al. (2008) had high expectations regarding the future applications of crowdsourcing in product design, product development, and configuration. Similarly, Corney et al. (2010a) claimed that human intelligence has powerful potential and should be employed directly at critical design steps. Such views further indicate that product conceptualization is an important arena for utilizing crowd wisdom to achieve innovative conceptual designs.

However, the integration of crowdsourcing in the product conceptualization phase is a complex task, as product conceptualization involves a series of consecutive processes (i.e., idea generation, concept evaluation and selection) and complex knowledge exchanges between different processes (Ulrich and Eppinger, 2012; Zha and Sriram, 2006). Therefore, crowdsourcing needs to be introduced in order to comprehensively consider the associated issues when performing crowdsourcing

in each design process. Specifically, crowdsourcing as an idea-generation approach leads to challenges in strategy formulation, platform construction, task design, and cheating control. Further, the crowdsourced conceptual designs are often ambiguous and large in number; hence, there are difficulties in data processing in the subsequent concept evaluation and selection processes. On the other hand, conceptual design is highly dependent on tacit knowledge (Araujo et al. 2001). The inherently imprecise and incomplete knowledge associated with the conceptual design phase hinders effective collaborations with other techniques and the formalization of a cross-functional collaborative design environment at this “fuzzy front-end” (Smith and Reinertsen 1997; Meniru et al. 2003). Regarding crowdsourcing, the function of mobilizing possible contributions leads to the supervision dilemma (i.e., casual to attract participation vs. strict to control quality); thus, the quality of entries is questionable, which further increases the burden of data screening and analysis. Hence, the integration of crowdsourcing in the conceptual design stage is expected to simultaneously handle these difficulties/challenges.

In summary, the integration of crowdsourcing is more inclined to the creation of a holistic crowdsourcing environment for product conceptualization, where each conceptual design process is studied fully, and the inherent problems of conceptual designs and crowdsourcing are jointly considered. The following important issues have to be addressed well.

1. How to involve crowdsourcing to facilitate concept generation for the creation of innovative concepts: Currently, crowdsourcing offers only a

basic conceptual scheme to build the connections between project assigners, online mediators, and contributors. The specific requirements and detailed operations need to be tailored for the concept generation process. Therefore, a crowdsourcing platform specifically meant for concept generation and collection needs to be established. Further, the inherent problems of crowdsourcing (i.e., lack of control over the quality of entries and lack of deliberate considerations about task design) need to be carefully addressed.

2. How to implement concept evaluation and selection in a crowdsourcing environment: Conceptual designs are extremely subjective and are represented in multiple formats (e.g., graphic model, textual description). Therefore, it is quite hard to quantify conceptual designs. In addition, crowdsourcing responses are often large in number and varied in quality. These two aspects lead to difficulties in concept evaluation and selection in a crowdsourcing environment. Thus, a method that can cope with crowdsourced conceptual designs in a quantitative and reliable manner is needed.
3. How to verify crowdsourced conceptual designs in terms of innovativeness: The sense of innovation is rather subjective and varies with personal preference and prior experiences. Thus, finding reliable ways to assess product innovation becomes vital. However, the definition of “innovativeness of conceptual product design” is still vague. This impedes the further exploration of the measurement and scientific assessment of product innovation. On the other hand, conceptual designs are extremely incomplete and ambiguous; therefore, understanding and evaluating them

properly are challenging. Thus, an innovativeness estimation approach is required to handle these practical issues.

This thesis presents a formal study of these three issues.

## **1.2 Objective and Scope of Research**

The objective of this research is to explore a product conceptualization strategy for utilizing crowd wisdom to facilitate product innovation. The proposed research is envisaged as being able to realize an innovation-driven concept generation process with a manageable crowdsourcing application, an effective and efficient concept evaluation and selection process in a crowdsourcing environment, and a well-defined concept retention process with a reliable measurement of the innovativeness of conceptual product designs. The overall anticipation is the establishment of a holistic crowdsourcing-based product conceptualization environment.

With respect to the research scope, this thesis concentrates on the product conceptualization phase and relies on the integration of crowdsourcing to facilitate product innovation. Therefore, the processing/analysis targets are the conceptual designs contributed by the crowd, and the expected outputs are the promising innovative concepts. The scope of research is as follows.

1. *A crowdsourcing platform for concept generation.*

This platform is intended to utilize crowdsourcing to facilitate the creation of innovative designs during the concept generation process. Therefore, the basic scheme of crowdsourcing will be extended into a well-organized

system with careful research on essential crowdsourcing elements. A standard procedure for innovation target re-analysis and decomposition and an elaborate scientific task design process will be established. A cheating monitoring strategy to realize control over the participation behaviors will also be proposed.

2. *A concept evaluation and selection approach in a crowdsourcing environment.*

This approach is intended to identify the promising concept candidates among the crowdsourced conceptual designs. To realize this goal, concept screening and evaluation are required to deal with the crowdsourcing responses. In particular, an information extraction procedure will be developed to extract conceptual designs from the web-based crowdsourcing platform. A sound concept representation strategy will be formulated to re-organize the crowdsourcing results (originally in various formats) into a unified format. Prior to the decision-making process, a concept clustering process will be deployed to simplify the comparison of the crowdsourced concepts.

3. *An innovativeness estimation strategy for crowdsourced conceptual designs.*

This strategy focuses on the in-depth examination of the identified promising concept candidates with respect to innovativeness. It will contribute to the definition of the “innovativeness of conceptual product design”. Moreover, an enhanced innovation assessment method will be developed that involves an estimation method that can deal with fuzzy and uncertain evaluation results.

### 1.3 Significance of the Research

The fulfillment of the research objective will contribute to the following research areas.

1. *Exploratory research of crowdsourcing in product design and development (PDD).*

While practitioners have gradually realized the expertise distributed among the crowd, the theoretical and methodological research on crowdsourcing has not been fully explored to date. This research is positioned to make a pioneering contribution by elucidating the prospect of crowdsourcing in PDD on a theoretical level and by supporting the creation of innovative products on a practical level. Product developers and innovation practitioners are the stakeholders and potential applicants of this research.

2. *Development of a holistic crowdsourcing environment for product conceptualization.*

This involves the careful study of the specific problems caused by the integration of crowdsourcing in each conceptual design process and the establishment of novel or improved knowledge consolidation and processing methods/approaches to tackle these problems. Therefore, technical contributions in realizing such a holistic crowdsourcing-based product conceptualization environment are expected.

These two areas cover the significance of this study in general. In Chapter 7 of the thesis, the contributions that fall within these two areas will be distinctively stated.

## 1.4 Organization of the Thesis

This thesis is organized as follows (please see Figure 1.2).

- Chapter 1 introduces the background, objectives, scope, and significance of this research.
- Chapter 2 presents a comprehensive review of the existing literature. The importance of the product conceptualization phase is intensively investigated, with an indication of the important role of product innovation in achieving effective and competitive conceptual designs. Based on the thorough analysis of the success factors of product innovation, the potential of crowd wisdom in facilitating product innovation is revealed. Subsequently, existing crowdsourcing studies are carefully reviewed, and the directions for future research on crowdsourcing in product conceptualization are discussed. The directional orientation and grounding of this research are established at the end of this chapter.
- Chapter 3 constructs the conceptual framework of the proposed product conceptualization strategy, which comprises three sub-systems: the web-based knowledge acquisition platform (WKAP), the artificial intelligence-based innovative concept discovery platform (AI-ICDP), and the concept learning and retention platform (CLRP). Detailed explanations of each sub-system are provided in this chapter. In addition, the general structure and specific procedures for each sub-system are outlined to further assist in the introduction of each sub-system.

- Chapter 4 explains the WKAP sub-system. The core of this sub-system is a crowdsourcing development approach, which provides a well-organized crowdsourcing platform with deliberate considerations of target analysis, task design, and cheating control. To demonstrate the effectiveness of the proposed approach, a case study of an innovation project dealing with future Personal Computer (PC) design is presented.
- Chapter 5 introduces the AI-ICDP sub-system. In this sub-system, the crowdsourced concepts are investigated further to identify the promising concept candidates. Since the conceptual designs are often in various formats and in large numbers, artificial intelligence techniques are considered to assist in the concept screening and evaluation process. A concept evaluation and selection approach based on data mining and domain ontology is developed specifically for dealing with the crowdsourced designs. In addition, a numerical illustration based on the future PC design project is provided.
- Chapter 6 describes the CLRP sub-system. The core of this sub-system is an innovativeness estimation approach for conceptual product design. Through the examination of the identified promising candidates, concepts with leading advantages in terms of innovativeness are considered to be retained for future PDD. The case study of future PC design is used to demonstrate the capability of the proposed approach in processing the concepts selected in Chapter 5.
- Chapter 7 concludes the thesis with a summary of the research findings, discussions, and directions for future research.

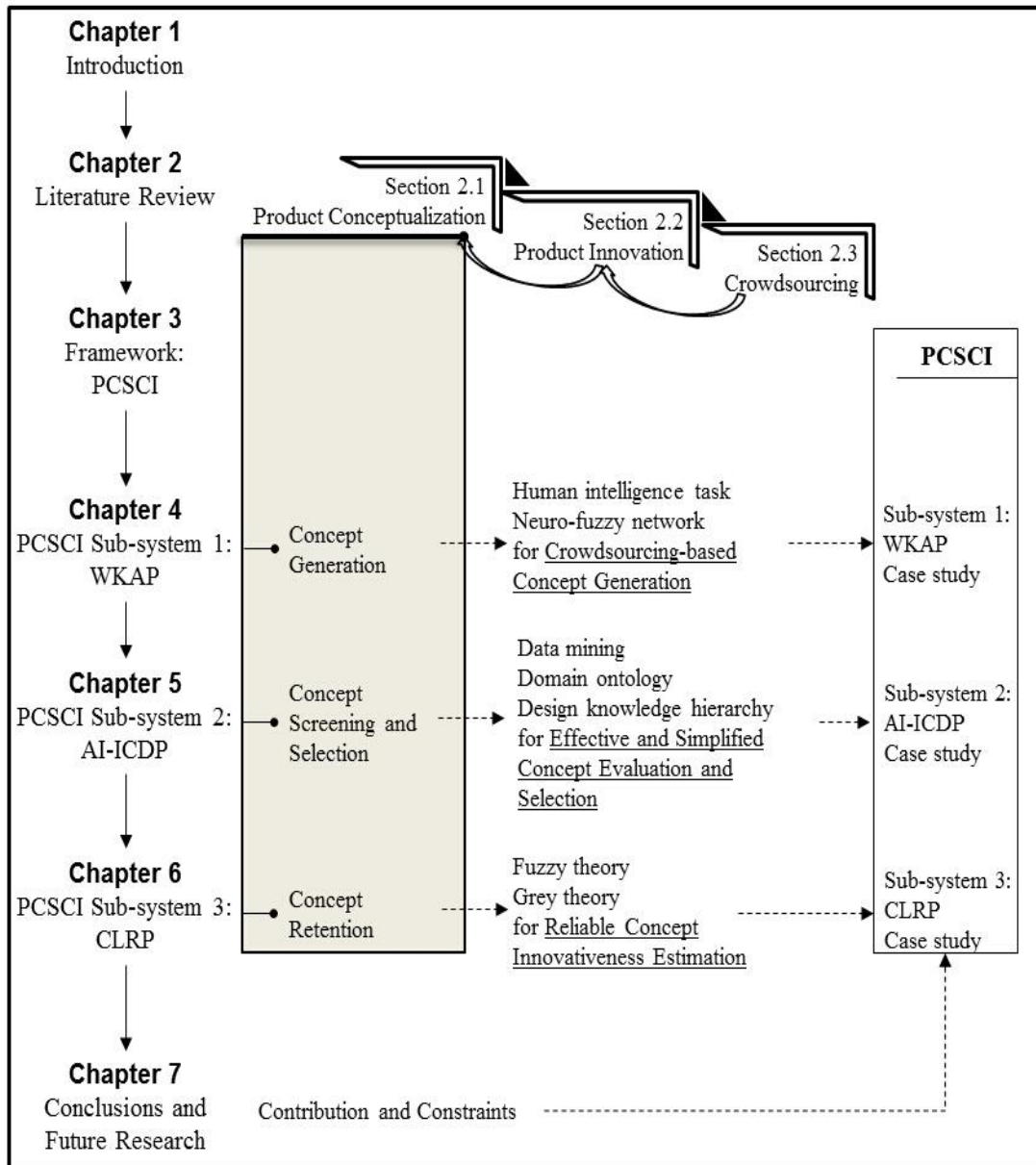


Figure 1.2 Organization of the Thesis

## Chapter 2 Literature Review

This chapter presents the detailed background of the research that serves to establish the context of this thesis. Section 2.1 explains the importance of the product conceptualization phase in product design and development (PDD). The essential processes and existing strategies in product conceptualization are reviewed, and the development trend of achieving innovation in the conceptual design stage is identified. Section 2.2 explores the implementation methods of product innovation in the initial design stage by dissecting the nature of product innovation; further, insights about the power of external resources and crowd wisdom are provided. In Section 2.3, approaches relevant to crowdsourcing (which is recognized as an emerging powerful resource solicitation method) are critically reviewed. The huge potential and uniqueness of crowdsourcing for fostering creativity, especially in the conceptual design stage, are identified. This finding inspires this study and encourages further efforts to leverage crowdsourcing in product conceptualization in order to drive innovative conceptual design. The research problem is stated in Section 2.4.

### 2.1 Product conceptualization

In this section, the following aspects of product conceptualization are presented: how to understand product conceptualization; important processes of the conceptualization phase; and the existing strategies for effective product conceptualization.

### **2.1.1 Basic understanding of product conceptualization**

In new product development (NPD), product conceptualization is the initial stage in which rough product design ideas are delineated for further development and testing. It can be perceived as the process of conceiving the attributes of artifacts. At the fuzzy front end, it is not easy to establish clear boundaries for the conceptualization phase. According to Ulrich and Eppinger (2012), product conceptualization should begin with the identification of the target market and end with the concepts describing the form, function, and features of a product. Yan et al. (2011) asserted that concept generation deserves more attention and should be studied at the beginning of the conceptualization phase. In short, it is widely accepted that the conceptualization phase occupies an extremely important position in the whole product life-cycle. Product conceptualization is estimated to account for over 75% of the costs incurred during product development (Alting and Legarth, 1995). The data derived from the industry also indicates that about 80% of the lifecycle cost is determined during the conceptual design stage (Smith and Reinertsen, 1997). Because of its extremely important role in PDD, the conceptual design phase has attracted much research attention in the past few decades.

However, conducting research in the conceptual design stage is challenging. On the one hand, the fuzzy nature of this stage necessitates an integrated analytical perspective to consider all the facets involved. According to Yan et al. (2006a), product conceptualization is a complicated process that involves multi-disciplinary knowledge sources that possibly overlap or conflict with one another. Similarly, Rodgers et al. (1999) claimed that a focus on communication and coordination

among the distributed resources rather than on individual capability alone is more important in the conceptual design stage. Therefore, it is practically an intricate issue to study product conceptualization, since the knowledge sources, as well as the interrelations among them are complicated. On the other hand, conceptual design is highly dependent on the designers' tacit knowledge (Araujo et al., 2001). This suggests the needs to understand the tacit knowledge residing within designers, to seek computer assistance to formalize this sort of knowledge, and to allow effective interpretation of data processing and decision-making. However, the inherent impreciseness and incompleteness of the designers' knowledge pose challenges to the integration of quantitative/intelligent techniques and increase the difficulties in handling conceptual design, while simultaneously necessitating the introduction of more deliberate methodologies to tackle this problem.

In short, the importance of product conceptualization is undisputed, and greater effort is required to better define, parse, and improve product conceptualization.

## **2.1.2 Essential activities of product conceptualization**

In this section, the essential activities of product conceptualization are introduced mainly from the following aspects: concept generation, concept screening and evaluation, and concept retention.

### ***2.1.2.1 Concept generation***

Concept generation is the development of design concepts. For a comprehensive analysis of concept generation, the details or concerns involved in this process are presented here. In particular, how to identify design motivation, how to assess

input information, how to manage design knowledge, and how to form concepts are discussed.

### Motivation identification

A well-defined design motivation could lead to a high chance of a successful product design. For companies suffering from a development bottleneck, the discovery of a potential new chance could offer them a head start in exploring unknown markets and seizing more market share. Ohsawa (2002) proposed the concept of “chance discovery,” which is intended to investigate underlying but important chances during scenario development. Various subsequent studies proposed the facilitation of chance discovery in creative product design. For example, Kushiro and Ohsawa (2005) established a new scenario elicitation method that used requirements engineering methods in chance discovery. Further explorations of the application of text mining techniques to assist chance discovery were conducted by Ohsawa (2003a, 2003b). Moreover, an innovation support system based on chance discovery was developed by Wang et al. (2012a). Through these efforts, unnoticed situation or opportunities are expected to be identified, which could form the design motivation that fosters promising product concepts.

### Information/Inputs assessment

With regard to the information inputs of the concept generation process, two facets of information are critically important: the information from customers/end-users and the information from designers.

Customer requirements (customers' voice) undoubtedly form an essential concern, which could mirror the market trend. Competence in capturing dynamic customer needs and integrating them into the conceptual design is deemed to be an absolute advantage for gaining competitiveness. However, the quality of information provided by customers/end-users is quite uneven; hence, an analytical assessment of customer-related inputs is needed. Kärkkäinen et al. (2001) conducted a study to summarize and analyze 10 assessment tools related to customer requirements. Increasingly advanced techniques such as design taxonomy (Morris and Stauffer, 1994), artificial neural network (ANN) (Chen et al., 2002) and sorting techniques (Shieh et al., 2008) have been applied in related areas to facilitate the processing of the information from customers. Customers are not always able to articulate their requirements. This leads to further difficulties in processing or using this kind of information. To tackle this problem, a design approach utilizing adaptive conjoint analysis was developed to help customers assert their needs, define variations, and visualize their options (Tseng and Du, 1998). Moreover, various strategies and approaches (e.g., a fuzzy-inference-based system (Harding et al., 2001)) were proposed to assist in the translation of poorly expressed requirements into clearly quantifiable needs. Instead of focusing on how to improve the information processing methods, some researchers suggested a different way to utilize the information from customers/users better, which is to engage/involve target users in the concept generation process. This means that potential users can contribute their ideas and wisdom to build the design concepts for themselves. Thus, new themes such as "customer co-creation," (Schrage, 1995) "customer involvement," (Magnusson et al., 2003) "customer interaction," (Vandermerwe, 2000) and

“customer engagement” (The Advertising Research Foundation, 2006; Hollebeek, 2011) are emerging to guide a more user-centric concept generation process.

In addition to customers, designers are an important source of information. The designers’ ideas and opinions could directly outline a design concept. Moreover, the assessment of customer requirements relies on the designers’ experience and knowledge. Nevertheless, as empirical knowledge, the information provided by designers may not be always reliable; hence, this information needs to be used carefully. To tackle this issue, various approaches for assisting designers have been explored. For example, Lin et al. (2008) proposed a framework that integrated the analytic hierarchy process (AHP) and the technique for order preference by similarity to ideal solution (TOPSIS) to help designers in the effective evaluation of customer requirements. Additionally, to support designers and extend design knowledge, design guidelines have been established for universal design through data mining, especially association rule learning (Sangelkar et al., 2012).

With the development of information technology, the information source for concept generation (such as online community information) is expanding, which further increases the diversity and complexity of the information involved in concept generation (Lee et al., 2012). Moreover, additional considerations centered on qualitative and subjective information such as affective design (Huang et al., 2012), user friendliness, and brand loyalty (Wang and Tseng, 2011) are involved in enhancing the processing of this kind of information. Further, multiple disciplines (e.g., engineering, managing and evolving the system and software concerns

(Elliott, 2000)) are incorporated at the conceptual design stage to account for important concerns during the initial stage of a project.

### Knowledge management

Concept generation needs to acquire and process much information from multiple sources. Thus, it can be regarded as a knowledge-intensive process. Accordingly, how to manage (e.g., gather, transfer, analyze) design knowledge effectively has been an important issue. Apak et al. (2012) suggested that knowledge management can be a source of competitive advantage. In particular, knowledge integration, which is the process of translating raw knowledge into actionable knowledge and integrating external and internal knowledge, is useful in improving the competency of firms. Thus, firms can harness outside ideas to advance their own businesses while leveraging their internal ideas outside their current operations (Chesbrough, 2003). Moreover, knowledge innovation is an important factor that leads to competitive advantage (Pisano and Wheelwright, 1995; Yang, 2005). By converting tacit knowledge into explicit knowledge, new knowledge can be created (Nonaka and Takeuchi, 1995).

### Concept formation

How to effectively form the conceptual design is a crucial issue in the concept generation process. Various methods or tools have been proposed to assist in the formation of design ideas. Specifically, brainstorming, which involves a set of process-driven guidelines, is an intuitive way of eliciting design ideas and increasing the initial idea pool. Brainstorming is widely adopted for PDD in

industry (Sutton and Hargadon, 1996; Kelley and Littman, 2001). Sketching is another powerful tool for presenting design concepts and is often considered as “a language for handling design ideas,” (Tovey et al., 2003) “a way to mentally offload concepts,” (Romer et al., 2000) etc. An exploration centered on brainstorming, morphological charts, and sketching was performed to examine the concept generation process (Yang, 2009). A storyboard is another design representation method similar to sketching. Because of its strength in graphic illustration and building communication among design team, clients, and future users, it is particularly useful in the initial design stages (such as scenario setting) and is treated as an important channel for forming design ideas (van der Lelie, 2006). Moreover, in-depth examination and communication during the concept formation stage are strongly suggested for understanding and capturing the design concepts better. Focus groups, interviews, and requirement meetings are recognized as effective techniques to look deeper into the design thinking underlying the generated concepts (Carrol, 2000); these are considered as crucial tools for concept evaluation and selection.

In general, concept generation is a significant process for the discovery of potential chances for successful product design. As an initial concept formation stage, it requires knowledge inputs from multiple sources and is a knowledge-intensive process. Nonetheless, the current information inputs (mainly from consumers and designers) may no longer meet the needs of PDD in a rapidly developing information age, and an expansion of the knowledge sources has become a necessity. This necessitates a rethinking of knowledge management in this problem context.

### ***2.1.2.2 Concept screening and evaluation***

In practice, concept screening and evaluation are combined, since the screening process is built on evaluation. Concept screening is a convergent process of narrowing down a set of design alternatives. It is considered a pivot in identifying competitive product concepts. Some of the commonly used concept screening methods in design practice are summarized in Table 2.1. Generally, screening models involve checklists and scoring methods (Cooper and de Bretani, 1984; de Bretani, 1986). To determine the concepts with market competitiveness, the identified market need should be emphasized, and relevant criteria should be highlighted in the selection stage. Gluck and Foster (1975) reported that marketing criteria play a crucial role in involving financial considerations in the new product proposal, and that the production and technical synergy may lead to low-risk and incremental product updates that fit existing business activities. However, marketing criteria are very complex. It has been pointed out that the risks, opportunity costs, relationship with other product developments, and nonmonetary aspects (e.g., influence of human and organizational behavior) also need to be studied in the concept screening stage (Baker and Albaum, 1986; Baker and Freeland, 1975; Souder, 1978). The integration of these facets should be based on specific project requirements. To differentiate these concerns, weighting methods are introduced to assign proper weights/priorities/indices to different concerns/criteria or even designers in the screening strategy (Muncaster, 1981).

Table 2.1 Methods for Concept Screening (Ulrich and Eppinger, 2012)

<b><i>External decision</i></b>	Concepts are turned over to the customer, clients, or some other external entity for selection.
<b><i>Product champion</i></b>	An influential member of the product development team chooses a concept based on personal preference.
<b><i>Intuition</i></b>	The concept is chosen by its feel. Explicit criteria or trade-offs are not used. The concept just seems better.
<b><i>Multivoting</i></b>	Each member of the team votes for several concepts. The concept with the most votes is selected.
<b><i>Web-based survey</i></b>	Using an online survey tool, each concept is rated by many people to find the best ones
<b><i>Pros and cons</i></b>	The team lists the strengths and weaknesses of each concept and makes a choice based upon group opinion
<b><i>Prototype and test</i></b>	The organization builds and tests prototypes of each concept, marking a selection based upon test data
<b><i>Decision matrices</i></b> (e.g. Pugh concept selection (Pugh, 1990))	The team rates each concept against pre-specified selection criteria, which may be weighted.

Nonetheless, how to measure qualitative or experience-dependent parameters, such as the importance of certain design criteria (e.g., in the decision matrices method) and the influence of certain designers (e.g., in multi-voting and pros and cons methods), and accurately convert them to quantitative numbers becomes an issue. To address this problem, a number of solutions have been explored, such as fuzzy set theory and AHP, which show advantages in dealing with weight calculation. An integrated model based on fuzzy set and AHP specifically intended for weight calculation and ranking in product design was proposed by Guo et al. (2010). Similarly, a fuzzy AHP approach was developed to improve the imprecise weights and ranking in product design (Kwong and Bai, 2002). In general, it appears that there is no definitive solution to improve the experience-dependent data completely. A more promising direction is to improve the data processing method and concept selection philosophy in order to get closer to good concepts. Several

iterations are often required to eliminate the influence of subjective factors (Ulrich and Eppinger, 2012).

With regard to concept evaluation, the procedure of scoring/rating is particularly important. Existing practices recommended a finer scale (e.g., 1–5 scale, 1–9 scale), which might be the most useful method for rating design concepts (Ulrich and Eppinger, 2012). Table 2.2 presents an example of a 1–5 scale. Normally, concept evaluation is executed by designers, engineers, or lead users. To control the uncertainty associated with this kind of experience-dependent score, some measures have been proposed to improve the reliability of the evaluation score. For example, the use of hierarchical relations is a useful way to demonstrate the criteria. For instance, the criterion “ease of use” does not provide sufficient detail to differentiate the concepts; therefore, it could be broken down into “ease of cleaning” and “ease of loading.” By expanding the criteria, a more explicit and systematic scoring system can be achieved, which could provide more reliable evaluation results. Moreover, comparative rating is widely adopted. The use of a reference concept would make the evaluation or judgment more evidential.

Table 2.2 1-5 scale in pure rating and relative rating

Performance to specified evaluation questions		Relative performance to reference concept	
Strongly disagree	1	Much worse than reference	1
Disagree	2	Worse than reference	2
Neither agree nor disagree	3	Same as reference	3
Agree	4	Better than reference	4
Strongly agree	5	Much better than reference	5

Although a large number of prior studies have discussed concept evaluation and screening, the inherent problems of conceptual designs (i.e., subjective knowledge,

qualitative assessment, tacit knowledge, and incomplete design information) have not been intensively and synthetically studied. The existing studies mostly adopt relatively detailed/complete designs to premise a reliable evaluation and selection. Thus, the existing research does not focus on dealing with conceptual designs in the concept evaluation and screening process.

### ***2.1.2.3 Concept retention***

The term “concept retention” is not used often in the context of product conceptualization. However, the nature of the complicated knowledge involved in product conceptualization leads to issues of knowledge learning and retention, which further increases the attention on retaining concepts that have a competitive edge. The application of case-based reasoning (Cheng, 2003) and TRIZ (Teorijz Rezhenija Izobretatel' Skitch Zadach, Theory of Inventive Problem Solving) (Ding et al., 2012) in product design indicates the need for retaining good design concepts in order to facilitate future product development.

To realize this objective, the key point is to fully understand what the competitive edge of a design concept is. With regard to design practices, competitive edge is relative and highly dependent on the firms’ intentions. Hence, various metrics (e.g., innovativeness/creativity (Yuan and Lee, 2014; Sethi et al., 2001; Molina-Castillo et al., 2011), design quality (Molina-Castillo et al., 2011), etc.) have been proposed to identify the advantages of conceptual designs and to provide references for concept retention. Through a comprehensive assessment of these metrics, concepts with obvious advantages can be identified and preserved for fostering better concepts for future development. However, how to define innovativeness or design

quality has been a subject of dispute in recent decades and remains a challenge for research in this field.

Apart from the essential product conceptualization processes discussed earlier, a series of additional activities are necessary during the product conceptualization phase, such as target market analysis, customer needs identification, and prediction (as shown in Fig. 2.1) (Ulrich and Eppinger, 2012). Prior studies on product conceptualization focused on the marketing perspective (e.g., market segmentation (Chan et al., 2012), commercial analysis (Yan et al., 2011), stakeholders concern (Yan et al., 2009b)) and customer-centric analysis (e.g., requirements elicitation and management (Chang et al., 2013), customer attributes (Yan et al., 2009c), lead user identification (Sann and Baier, 2012)) rather than on the direct handling of conceptual design itself. However, even the highest standard of detail design cannot compensate for a poor design concept (Yan et al., 2006b). Thus, greater focus on intensive management and the processing of conceptual designs might be required.

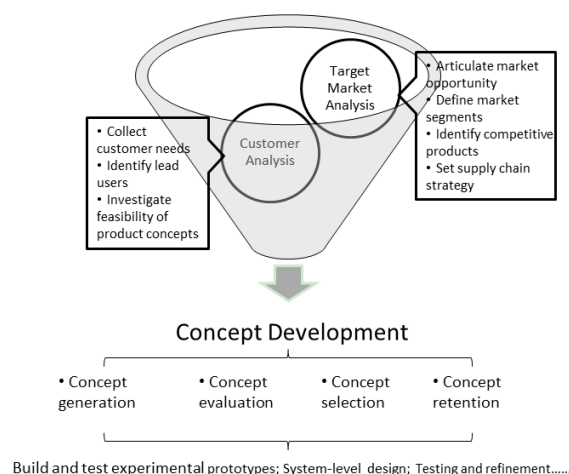


Figure 2.1 Concept development in a generic product development process (Ulrich and Eppinger, 2012)

### **2.1.3 Strategies for achieving effective product conceptualization**

Based on the different targets that a product conceptualization aims to achieve, the existing product conceptualization strategies could be generally classified into two categories: reactive strategies for improving product concepts to satisfy consumers, suppliers, or other market needs better; and proactive strategies for exploring design concepts that could lead the market or even create a new market.

#### ***2.1.3.1 Reactive product conceptualization strategies***

From the commercial perspective, a functional–commercial analysis strategy has been proposed to facilitate product conceptualization, especially in the selection of preferred concepts, through the integration of cost- and time-related concerns (Yan et al., 2011). Further, a more comprehensive strategy for product conceptualization was developed to achieve design concepts of optimal quality while incurring minimal cost in a short lead time (Chen et al., 2012). Moreover, a stakeholder-oriented innovative conceptualization strategy was proposed to integrate all related concerns (i.e., functional, cognitive, marketing, and commercial) in order to evaluate the product concept comprehensively (Yan et al., 2009a).

Several prior studies on product conceptualization that are centered on consumers examine human-centric product conceptualization focusing on the trade-off between design and consumers (Chang et al., 2010), the improvement of concept development methods for capturing consumers' needs better (Chen et al., 2013), the integration of design knowledge and organizational structure to facilitate human-centric conceptualization (Chong et al., 2009), and so on.

New strategies to meet the demand of product conceptualization using advanced intelligent technologies have been frequently reported in recent years. Some well-established techniques such as data mining (Yan et al., 2009b), web technology (Roy and Kodkani, 2000), and the concept of sustainability (Yan et al., 2009c; Chang et al., 2014b) are widely adopted/adapted for improving conceptualization strategies.

### ***2.1.3.2 Proactive product conceptualization strategies***

The role of proactive market orientation in the product success of firms has been recognized. Beverland et al. (2006) stated that most successful firms were found to be market-driving, instead of relying solely on relationships and reacting to changing market phenomena. From a market-driving perspective, innovatively creating new needs and solutions to lead the market with new products that could involve radical innovations could be considered as an important direction for product conceptualization (Kumar and Phrommathed, 2005). For this purpose, a number of knowledge-intensive and innovation-oriented conceptualization strategies have been proposed. A strategy for managing the knowledge related to product attributes with reference to hierarchical effects in order to achieve inherent innovativeness in product design was proposed by Lee et al. (2013). Moreover, customer needs forecasting was explored to embed the concern of consumers' adoption in the initial design stage in order to develop products with leading features (Lowe and Alper, 2015). A study that explored the use of knowledge integration in product development was conducted (Tsai et al., 2015), which suggested the impact of knowledge integration in developing creative products (Tsai et al., 2015).

Despite focusing on knowledge management, the ultimate target of these prior studies was product innovation. This could indicate the important role that product innovation plays in the product conceptualization of competitive products. By improving idea generation techniques and/or concept screening methods, it is possible to stimulate blooming ideas and facilitate the identification of more innovative concepts (Johne and Snelson, 1988). Several strategies have been suggested for integrating innovation concerns in the conceptualization phase, such as the integration of innovation-related factors, design thinking styles and computer support tools to re-define design activities and to select suitable creative strategies (Li et al., 2007), the development of an intelligent innovative design environment to facilitate effective concept generation and configuration (Zhao et al., 2006), and the use of a robust design support strategy to achieve creativity-based design processes with the help of modified interactive 3D design (Hu et al., 2014), to name a few. Therefore, leveraging product innovation considerations and measures to achieve effective and even successful product conceptualization appears to be a highly promising strategy.

## **2.2 Product innovation**

Over the last few decades, product innovation has been proven to be effective in increasing product value and has been widely implemented in various industries (Tohidi and Jabbari, 2012; Van Horne et al., 2006). In this section, current product innovation studies and the multi-faceted knowledge underlying the existing research are analyzed.

## **2.2.1 Overview of product innovation**

Product innovation is the creation of new products (characterized by new functions, new functional principles, fewer functions, and additional functions) as well as the improvement of existing products (Disselkamp, 2005; Ettl et al., 1984; Pleschak and Sabisch, 1996; Tidd et al., 2005; Reichwald and Piller, 2006). From the perspective of technological changes, product innovation can be classified as incremental innovation with changes based on learning from leading companies and radical innovation with changes new to the market (Freeman et al., 1982).

### ***2.2.1.1 Incremental improvements***

Incremental innovations occur more or less continuously in any industry or service activity, although at varying rates in different industries and over different time periods. They may often occur not so much as the result of formal research and development activity but as the outcome of inventions and improvements suggested by engineers and others directly engaged in the production process, or as a result of initiatives and proposals by users (Freeman et al., 1982). Normally, the technology required is not very different from the company's conventional business practices, and the production processes used are well-understood (Lynn et al., 1998). Several empirical studies examined the importance of incremental improvements in improving production efficiency (Townsend, 1981). The combined effects of incremental improvements have been identified to be significant in the steady growth of productivity over time.

In short, incremental innovation could be characterized by low technical and market uncertainty as well as incremental product changes based on knowledge,

experience, and capabilities that already exist in the company (Zirger and Hartley, 1994).

### ***2.2.1.2 Radical innovation***

Radical innovations give rise to new products for both the company and the market. They are the result of deliberate research and development activity, and may involve significant technological revolutions (Valle and Va'zquez-Bustelo, 2009). Normally, they are unevenly distributed over sectors and over time. Mensch (1979) stated that the appearance of radical innovations is concentrated particularly in periods of deep recession, which indicates the high expectations associated with the revolutionary changes made by radical innovation. Freeman et al. (1982) claimed that whenever radical innovations occur, they bring about big improvements in the cost and quality of existing products; thus, they can be considered as a potential springboard for the growth of new markets. However, while a radical innovation may have fairly dramatic effects, in terms of their economic impact, they are relatively small and localized, unless a whole cluster of radical innovations is associated with the rise of entire new industries and services. Strictly speaking, at a sufficiently disaggregated level, radical innovations would constantly require the addition of resources. Nonetheless, in practical terms, such changes are introduced only in the case of the most important innovations and with long time-lags, when their economic impact is already substantial (Freeman et al., 1982).

Thus, radical innovation could be characterized by a high degree of complexity in the new product requirements (which are as yet undefined) as well as a high degree

of uncertainty with regard to technology, customers' needs, and competitors' actions (Song and Montoya-Weiss, 1998; Lynn et al., 1996).

Considering these two types of innovations, it is clear that incremental innovation is relatively easy to attain, whereas successful radical innovation is hard to achieve. This is why incremental innovations are often preferred in design practices. Nevertheless, along with the adoption of emerging state-of-the-art techniques and philosophies, the environment tends to be increasingly favorable for radical innovations, and the spring of radical innovation seems to be coming (Chapman and Hyland, 2004; Shenhar et al., 1995).

### **2.2.2 Success factors of product innovation**

A review of the existing product innovation research on NPD reveals some factors that have significant impacts on innovation effects, such as customers, market, environment, etc.

#### ***2.2.2.1 Market-driven factor***

In the current competitive environment, whoever grasps the market grasps the initiative. The market provides a platform and opportunities for firms to become market leaders (Wang et al., 2012b). Therefore, companies strive to achieve continuous improvement and healthy growth in order to gain as large a market share as possible (Kok and Biemans, 2009). To survive in the complex and competitive market, both competition and collaboration are necessary and should be balanced well by the firms. On the one hand, competition with competitors incentivizes a firm's investments in terms of time and cost on product design and optimization (Cao and Yang, 2012), especially when new technologies are

launched or innovations are developed by competitors. Therefore, the pressure from competitors can lead to mutual improvements. Moreover, the formulation of management strategies should consider the industry competition situation (Norbäck and Persson, 2012), since in the planning of a new project, the control of the program schedule and the arrangement of production should refer to the development of the whole industry. On the other hand, collaboration is important for product innovations (Nieto and Santamaria, 2007). Collaboration can be classified into cooperation with competitors, seeking support from research institutions, soliciting opinions from clients, sharing resources with suppliers, and mobilization of various stakeholders (Sarpong and Maclean, 2012). Wu (2012) showed that collaboration with competitors always results in negative effects. Therefore, collaboration with suppliers, clients, and research institutions (i.e., external resources) might be more feasible.

#### ***2.2.2.2 Environmental and societal factors***

Environmental design and societal design are new trends in product development. Along with the intense attention to sustainable development, environmental and societal concerns are becoming increasingly important in driving improvements and inventions in product design.

Sustainable development is the focus of today's world as environmental deterioration is severe. In the realm of product innovation, green innovations have been advocated widely, and environmental issues are increasingly gaining attention as indicated by the related theories (e.g., Design for Environment, Design for Excellence) and analytical tools (e.g., Life Cycle Assessment) (Tseng et al.,

2012). Life cycle thinking is the main policy that guides innovations in the environment-friendly direction. In particular, life cycle costing (which combines cost analysis and environmental thinking) is much appreciated in product innovation (Krozer, 2008).

With regard to the societal dimension, the problems are mainly related to the overload of engineers, health of manufacturing workers, and compensation system. To examine problems such as the continuous working time, salary system, and technical knowledge, a study that investigates the operation efficiencies of employees was conducted. Additionally, socio-techniques were developed by studying the relations between social techniques and innovations (Ngo and O'Cass, 2012).

### **2.2.2.3 “Extensive consumers”**

Among the various factors affecting product innovation, the customer is the most important one because the use of customers’ talents could deliver superior service and enhance productivity (Lovelock and Young, 1979). The use of customers’ talents has been regarded as a means to achieve competitive advantage (Prahalad and Ramaswamy, 2004).

As integral participants in design activities, customers could directly affect the success of a new product via the degree of customer satisfaction (Ngo and O'Cass, 2012; Szainfarber et al., 2010). Hence, in design practices, customers have become a source of information for concept generation. Customer requirements are necessary inputs for product improvements and modifications. Various innovation models have been developed based on the assumption that the customer is the

starting point and the end point of a design process. Generally, customer-centric innovations can be divided into five categories, viz. improved customer requirements acquisition method (Kärkkäinen et al., 2001), efficient and effective customer need assessment models (Kärkkäinen and Elfvengren, 2002), advanced integration of customer opinions into concept generation (Smith et al., 2012), optimization of customer comfortability of product (e.g. interface design (Chen and Liu, 2005)) and product redesign (Smith et al., 2012) approaches based on customers. These methods and models point out the importance of customers to product innovation.

However, multi-faceted related personnel may have an impact on the innovation process (as discussed in Section 2.1.2.1), such as suppliers, partners, or competitors as addressed in Section 2.2.2.1 (Sarpong and Maclean, 2012). Therefore, the term “extensive consumers” is used to represent all groups of personnel who might be involved in and have an impact on design activities.

### **2.2.3 Crowd wisdom as an innovation source**

According to von Hippel (1988) and Parkinson (1982), customers could be the main source of innovative ideas. This implication increases the significance of the contribution of influential personnel (i.e., extensive consumers) (refer to Section 2.2.2). “Crowd wisdom” is proposed to cover the contributions/inputs of various design-involved personnel. In modern industries, vast amounts of knowledge are exchanged concurrently among different functions, with the participation of different stakeholders. The contributions could be from multiple sources.

Therefore, an expansion of the current innovation sources (mainly from customers and designers) is required (as discussed in Sections 2.1.2.1 and 2.2.2).

Strategies such as participatory design, open innovation, and value co-creation utilize outbound resources to extend innovation activities. It has been identified that these strategies can lead to many successful innovative outputs.

Participatory design (PD) is an important approach that involves the various associated stakeholders to ensure the final usability of products or systems (Garrigou et al., 1995). Collaborative system or collaborative design is the major arena for PD methods. For example, a new system has been developed for managing the cooperation between organizations and researchers (Timpka et al., 1995). A collaborative system has been developed to support the role-based user advocacy, formative evaluation, and change management in order to extend the relevant understanding of the users (Weng et al., 2007). In addition, software development is an important platform to involve users in the design process for producing a more user-friendly and effective user interface (Lyng and Pedersen, 2011). In order to achieve a better linkage between design activities and stakeholders, “boundary objects” are proposed to clarify objects in the participatory ergonomics (PE) design process (Broberg et al., 2011). These so-called boundary objects, such as computer-aided design (CAD) and virtual reality (VR), are tools that assist PE. These tools can match local and common needs and are robust in handling different situations (Bruno and Muzzupappa, 2010). Moreover, a systematic survey was conducted to define the involvement of different stakeholders from the top, middle, lower management (Vink et al., 2008).

The results highlighted the essential role of the inputs from ergonomists and employees. However, in some exceptional cases, it would not be appropriate to engage the real users. For example, during the development of educational software, students would be afraid to express themselves directly; therefore, fictional characters are used as representative users to elicit really useful opinions (Triantafyllakos et al., 2010). For products that aim to serve specific customers, PD is a good choice for bringing out ideas and design concepts (Demirbilek and Demirkan, 2004).

Open innovation is a paradigm in which firms combine external and internal ideas through internal and external paths in order to advance their technology (Chesbrough, 2003). It integrates multiple facets into a design project and establishes an information-sharing platform to connect with inbound and outbound resources. However, according to an empirical study by Huizingh (2010), too much openness could hurt a firm's performance and increase costs. Moreover, the adopters of open innovation are mostly large sized firms. This indicates the limitations of applying open innovation (Huizingh, 2010).

Value co-creation is defined as two-way information based on interactions between firms and stakeholders. It emphasizes the generation and ongoing realization of mutual firm-customer value (Fujioka, 2009). It views markets as forums for firms and active stakeholders to share, combine, and renew each other's resources and capabilities in order to create value. Generally, the co-creation of value can assist firms in highlighting the stakeholders' point of view and improving the front-end process of identifying stakeholders' needs and wants

(Lusch and Vargo, 2006). Moreover, co-creating the voice of customers has been one of the research focuses of co-creation in product innovation (Jaworski and Kohli, 2006). For the integration of crowd wisdom as innovation inputs, co-creation is a useful strategy to connect the target crowd and firms closely and create unexpected value during the deep interaction. However, a strong focus on the external organization could alienate the manufacturer from its inherent core competencies, which may result in an imbalance between investments and expected outputs (Lilien et al. 2002).

Based on the preceding analysis, the importance of the contribution/participation of multiple facets/functions/sectors is realized. Hence, the significance of crowd wisdom as innovation inputs is recognized. Supported by an investigation of some models and systems that successfully integrate crowd wisdom in product design and innovation, it is demonstrated that the integration of crowd wisdom could be an adoptable way to achieve better product designs. However, the studies in this field are still new and mostly instructional, and a formal intensive study on systematic and strategic utilization of crowd wisdom in PDD is lacking. Thus, there is significant space for further detailed research on the potential of crowd wisdom in product conceptualization.

## 2.2.4 Strategies involving crowd in product innovation

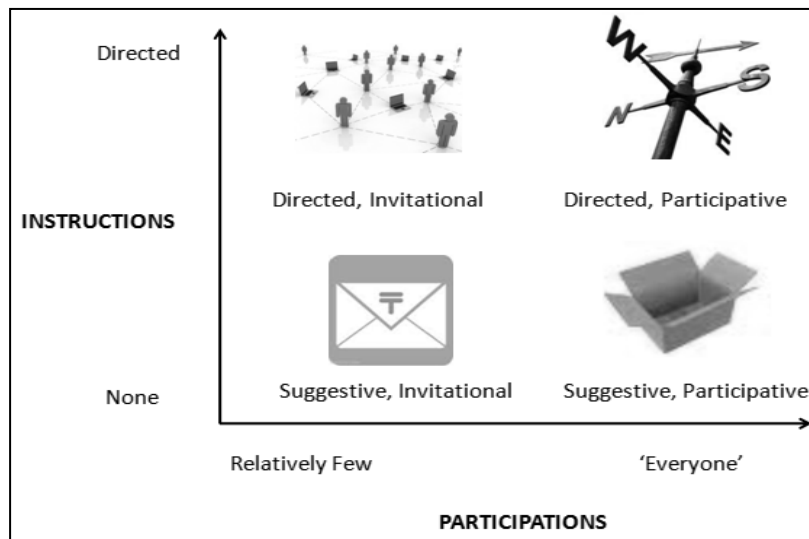


Figure 2.2 Classification of crowd involvement strategies (Sloane, 2010)

From the perspective of participation, crowd involvement can be classified into two levels: involving a specified target crowd (i.e., invitational) and involving anyone with interest (i.e., participative). From the perspective of required instructions, crowd involvement can be categorized into two levels: involvement with explicit requirements to give a clear direction for participants to contribute (i.e., directed) and involvement with no detailed instructions to give participants the full freedom to contribute (i.e., suggestive). Based on a joint consideration of these levels, the strategies involving crowd wisdom can be classified into four categories (see Figure 2.2).

The suggestive and participative mode is an innovative program with few instructions that is open to anyone who has interest in participating. The suggestive and invitational mode involves inviting pre-specified target individuals, teams, or organizations to freely contribute their ideas or opinions. The directed and

invitational mode involves inviting target individuals, teams, or organizations to submit their ideas or opinions on certain topics or requirements pre-specified by sponsors. The directed and participative mode requires addressing a particular problem, and anyone with interest can participate. A detailed comparison of these strategies is summarized in terms of the pros and cons of each strategy in Table 2.3.

Table 2.3 Comparison between four crowd involvement modes

<b>Strategy</b>	<b>Advantages</b>	<b>Disadvantages</b>
Suggestive/ Participative	<ol style="list-style-type: none"> <li>1. The breadth of ideas submitted will be vast;</li> <li>2. The number of ideas submitted can be staggering.</li> <li>3. This strategy is, for all intents and purposes, subject to the same expectations that an individual might have about a social media platform;</li> </ol>	<ol style="list-style-type: none"> <li>1. Secrecy is difficult and protection of intellectual property is almost impossible;</li> <li>2. Ideas submitted are likely to be incremental;</li> <li>3. Evaluation and selection are much more difficult than other types.</li> </ol>
Suggestive/ Invitational	<ol style="list-style-type: none"> <li>1. The number of ideas submitted can still be large;</li> <li>2. Evaluation and selection are simpler than in a suggestive model;</li> <li>3. As the participants are invited, it becomes much easier to protect ideas and define intellectual property;</li> <li>4. A suggestive, invitational model is less susceptible to issues that traditional “social media” sites bear.</li> </ol>	<ol style="list-style-type: none"> <li>1. The breadth of ideas submitted will be large but not as large as in the suggestive, participative model;</li> <li>2. Ideas submitted are likely to span the gamut from incremental to disruptive, but as a whole they are also more likely to be relevant to the strategic goals and needs and applicable to near-term needs</li> </ol>
Directed/ Invitational	<ol style="list-style-type: none"> <li>1. The depth of the ideas is much greater than in other forms;</li> <li>2. Many of the intellectual property issues and other confidentiality concerns have been addressed as the partnership developed;</li> <li>3. Ideas submitted within this framework are governed by your instructions rather than by the crowd.</li> </ol>	<ol style="list-style-type: none"> <li>1. The breadth of ideas submitted will be limited by the defined need or challenge;</li> <li>2. The number of ideas submitted is likely to be far smaller than in other formats, but the viability of the ideas is much greater;</li> <li>3. There is a risk that the firms within the trusted partnership and the participants in the program</li> </ol>

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		“know too much” and don’t stretch their thinking far enough.
<b>Directed/ Participative</b>	<ol style="list-style-type: none"> <li>1. The depth of the ideas is much greater than in other forms;</li> <li>2. Evaluation and selection are simplified because the topic or challenge is usually well defined;</li> <li>3. Depending on the topic and the breadth of interest and engagement, this model attracts as many participants and generates as many ideas as a suggestive, participative model.</li> </ol>	<ol style="list-style-type: none"> <li>1. The breadth of ideas submitted will be limited by the defined need or challenge</li> <li>2. As these ideas are often available on a public forum, the issues of intellectual property, secrecy and confidentiality arise.</li> <li>3. Ideas submitted as part of a directed, participative model are likely to incline to disruptive.</li> </ol>

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Given the objective of expanding innovation resources and exploiting systematic and manageable utilization of crowd wisdom (as identified in Sections 2.1 and 2.2), the directed and participative integration strategy attracts more research attention based on the comparison. This strategy is emphatically studied in this thesis as well. On the one hand, with a well-defined problem and explicit requirements, the concepts/solutions contributed by participants can be effectively controlled. At the very least, irrelevant information would be avoided. Since the design target is indicated, the evaluation and selection of information contributed by participants can also be simplified. On the other hand, the participative involvement mode helps to attract as many people with similar interests and relevant background as possible, and increased contribution may lead to a better chance of achieving better design concepts. Additionally, this strategy can be easily supported by software.

### **2.3 Crowdsourcing**

Crowdsourcing is an approach that uses the directed and participative integration strategy to aggregate the wisdom of the undefined online workforce. Compared to

conventional product development approaches, the results of crowdsourcing depend on the solvers' education level, capability, and initiative. However, crowdsourcing might be more efficient in terms of knowledge acquisition; thus, it has attracted increasing research attention in recent years.

### **2.3.1 Overview of crowdsourcing**

The term “crowdsourcing” was coined by Howe (2006) and is defined as “the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call.” It is an important method to draw upon the knowledge contributions of large numbers of people (Afuah and Tucci, 2012; Geiger et al., 2011).

In recent years, crowdsourcing has been applied widely in various industries, such as medicine and education (Brabham, 2009; Armstrong et al., 2012; Rossen and Lok, 2012). In the realm of PDD, crowdsourcing has been recognized as an effective way to aggregate a crowd's wisdom in order to create more chances to achieve better and improved design concepts (Simula and Ahola, 2014). Wikipedia (for collaborative content modification and extension),<sup>3</sup> Amazon's Mechanical Turk (for problem solving),<sup>4</sup> and iStockPhoto.com (for photography contribution)<sup>5</sup> are good examples of exploiting the tremendous number of Internet users to successfully improve product designs. P&G uses “InnoCentive”<sup>6</sup> to deal with its most challenging problems, and the problem solving rate has increased to 30%.

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<sup>3</sup> [https://en.wikipedia.org/wiki/Main\\_Page](https://en.wikipedia.org/wiki/Main_Page)

<sup>4</sup> <https://www.mturk.com/mturk/welcome>

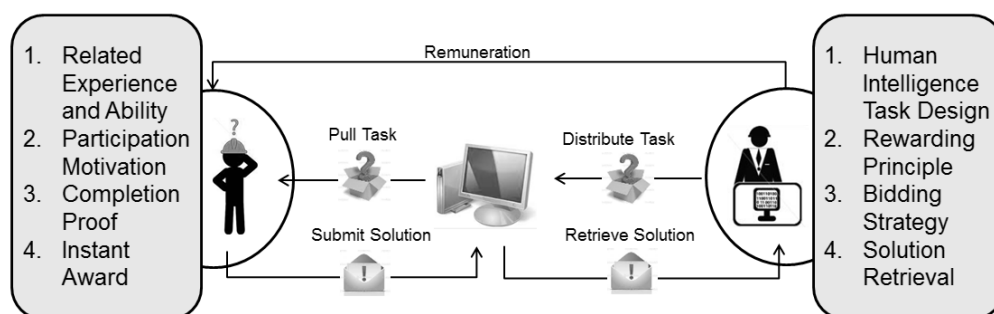
<sup>5</sup> <http://www.istockphoto.com>

<sup>6</sup> <http://www.innocentive.com>

Dell has set up an IdeaStorm<sup>7</sup> platform to collect comments and suggestions from Internet users for all Dell products. Thus, crowdsourcing appears to be a promising way to solicit external resources to improve product competitiveness (Doan et al., 2011; Cook, 2008). Some research efforts have been devoted to crowdsourcing, the scope of which includes the authentication of crowdsourcing's power in acquiring useful data (Armstrong et al., 2012) and the identification of factors that may influence the crowdsourcing effect (Shao et al., 2012).

### 2.3.2 General development of crowdsourcing platform

Generally, crowdsourcing can be schematically depicted as in Figure 2.3. The employer/assigner (right side) submits a task (human intelligence task [HIT]) to a mediator, viz. the crowdsourcing platform, and defines the design requirements, reward rules, task duration, etc. Online workers/providers (left side) who are interested in this task can work on it and submit their solutions to the mediator after completing the task. These solutions are forwarded to the employer who remunerates the participants if their solutions are approved (Chang et al., 2014a).



**Figure 2.3** Typical crowdsourcing scheme (Chang et al., 2014a)

A crowdsourcing platform is often built upon Web2.0 to realize the connection and interaction between design projects and participants. Most existing crowdsourcing

<sup>7</sup> <http://www.ideastorm.com/>

platforms are used for online surveys or general problem-solving purposes (Ebner et al., 2009; Chanal and Caron-Fasan, 2008). For example, Amazon's Mechanical Turk is a typical and widely adopted crowdsourcing platform. Owing to its richly functional HITs, it can be used for most problem-solving projects. Moreover, there are some crowdsourcing platforms for particular use, such as Wikipedia for collaborative content modification and extension, iStockPhoto for photography collection and purchase, and Kickstarter<sup>8</sup> for fundraising. Several platforms aimed at product design projects such as crowdSPRING<sup>9</sup> and designboom<sup>10</sup> have been developed.

The design of HITs is different across crowdsourcing platforms. Especially for interface design and workload management, different platforms may have very different arrangements. However, the basic task design principle is similar: easy-to-understand and easy-to-complete. Therefore, question types such as single/multiple choice, sorting, and word entry, are commonly employed during the crowdsourcing platform development. This indicates that the available task types are actually limited.

### **2.3.3 Crowd segmentation analysis**

Technically, the “crowd” in crowdsourcing represents an undefined online workforce. The crowd could involve anyone who would like to contribute their solutions to the project, regardless of their background and specialty. Referring to Hayek (1945), “the knowledge of the circumstances of which we must make use

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<sup>8</sup> <https://www.kickstarter.com/>

<sup>9</sup> <http://www.crowdspring.com/>

<sup>10</sup> <http://www.designboom.com/design/>

never exists in concentrated or integrated form but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess.” To fully understand the possible sources of contributors, a segmentation analysis is proposed.

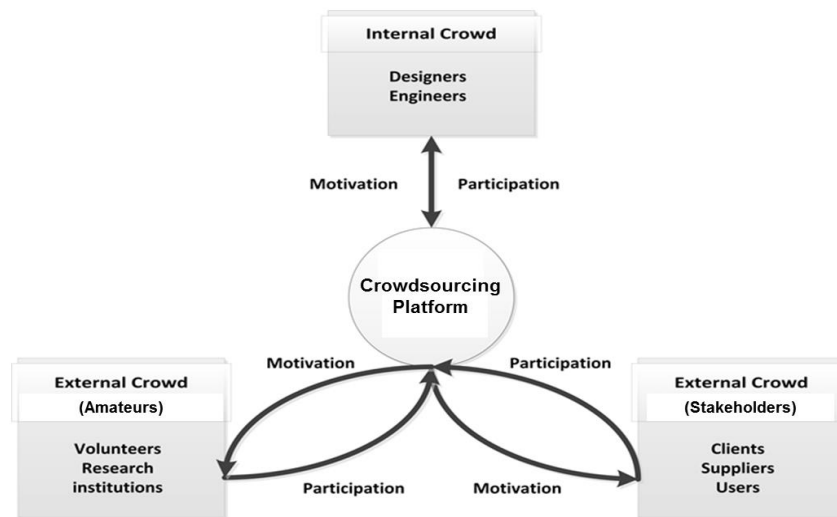


Figure 2.4 Crowd segmentation (Sloane, 2010)

As presented in Figure 2.4, the crowd that might be involved in a design project belongs to three main categories (Sloane, 2010). The crowd regardless of whether it is within or outside the company can be the participants. The internal crowd is constitutively simple, mainly including designers, engineers, and design managers from the R&D sector; however, the external crowd may have very different backgrounds and should be subdivided. According to their background and specialty, external participants may be stakeholders of a project or amateurs with strong related interests. A detailed comparison of the different crowd segments is presented in Table 2.4.

Table 2.4 A comparison between different crowd segments (Corney et al., 2010a; Sloane, 2010)

<b>Crowd</b>	<b>Characteristics</b>	<b>Motivations</b>	<b>Participation</b>
Internal “Expert”	Good knowledge in this area Rich experience in such project Familiar with the crowdsourcing platform Familiar with HIT design <b>Expectable professional opinions/ideas/solutions</b>	Job duty Personal interest Recognition from the management level	Active
External Stakeholders “Most people”	Some knowledge in related areas Rich experience in this industry New to the crowdsourcing platform New to the HITs <b>Referential beneficial solutions/ideas</b>	Mutual benefit Personal interest Monetary reward	Active
External Amateurs “Vast majority”	Possibly deep knowledge in related areas Possibly much related experience and practices New to the crowdsourcing platform New to the HITs <b>Surprising solutions/ideas</b>	Monetary reward Personal interest Recognition from professional organizations Connection with domain professionals	Driven

Despite the crowd segmentation analysis, crowdsourcing is often used without a deliberate consideration of what constitutes a “suitable crowd.” The significance of crowdsourcing lies in the large number of contributors; therefore, the involvement of as many participants as possible is a commonly adopted manner of functioning. However, broader participation does not always lead to better crowdsourcing results. Because of the anonymous nature and loose participation management, a fair amount of crowdsourcing information is actually invalid in practice. Therefore, the concept of “effective participation” is proposed in this study, which highlights that the application of crowdsourcing should focus on the broad and effective contribution from a distributed crowd.

### **2.3.4 Potential of crowdsourcing for fostering creativity**

Florida (2003) stated that creativity could be exhibited through “increased spending on research, high-tech startups, and a new social milieu, all converging in an age of pervasive creativity permeating all sectors of society.” Cook (2008) had a similar view that increased participation could be a contribution revolution as crowds may offer the potential for creativity. In this section, the potential of crowdsourcing for creativity in terms of seeking creative solutions and developing creative crowdsourcing approaches is further identified.

Firstly, crowdsourcing is useful in devising innovative or better solutions. For example, Heipke (2010) pointed out that the crowdsourcing technique is helpful in geospatial mapping and change detection in real time with considerable data at a low cost. Similarly, the general public is viewed as an important data source for hydrologic measurements (Fienen and Lowry, 2010). In the manufacturing industry, crowdsourcing provides an opportunity to activate crowds to assist in the identification of efficient product and material cycles (Heyer et al., 2013). In website building, crowdsourcing can be an efficient approach for usability testing (Liu et al., 2012a). Moreover, crowdsourcing has been successfully used to obtain optimal resource planning (Bazilian et al., 2012) and to perform fast and reliable information retrieval (Alonso and Mizzaro, 2012). Thus, crowdsourcing appears to be very important in discovering better solutions using crowd wisdom, and the integration of various techniques (e.g., collective intelligence (Morris and Picard, 2012), probabilistic graphical model (Bachrach et al., 2012; Lin and Weld, 2012), human-computation (Rossen and Lok, 2012)) has been considered to enhance the

applicability of crowdsourcing. Therefore, it is worthwhile to explore crowdsourcing approaches for supporting product innovation in order to achieve better design solutions.

Secondly, diverse creative studies have focused on formalizing and improving crowdsourcing. For an accurate and efficient crowdsourcing, a hybrid human-machine approach has been used to allocate the jobs (Wang et al., 2012a). To deal with the crowdsourcing cost and to improve the performance of real-time crowdsourcing, analytical methods (Bernstein et al., 2012) and mathematical analysis (Hirth et al., 2013) have been studied. A crowdsourcing data analytics system has been developed to estimate the accuracy of generated results (Liu et al., 2012b), and an investigation into endogenous entry has been proposed to incentivize high-quality outcomes in crowdsourcing environments (Ghosh and McAfee, 2012). In addition, a learning algorithm was integrated to predict the wisdom of crowds and approximate the crowd's opinions (Ertekin et al., 2012). A virtual valuation function, which depends on the distribution of the contestants' skills and the number of contestants, was proposed to optimize crowdsourcing contests (Chawla et al., 2012). In short, the issues of participation performance, task (job) allocation, and entry quality in crowdsourcing have been examined. The solutions to these problems have been explored recently. However, these studies are sporadic and not in-depth, and they are unable to simultaneously consider the abovementioned issues. Therefore, a strategic consolidation of these concerns in the development of the crowdsourcing platform would be worthwhile.

### **2.3.5 Anticipation of future development of crowdsourcing in product conceptualization for fostering innovative product design**

The history of crowdsourcing is rather short, since this term was coined by Howe in 2006. Although relatively new, crowdsourcing is emerging as an active and attractive field involving models, techniques, and applications of greater diversity. The rich diversity of facets that crowdsourcing may assume is revealed in business practices (Hammon and Hippner, 2012). An increasing number of firms are integrating crowdsourcing into their business processes. For example, Threadless.com<sup>11</sup> enables the crowd to create their own designs for t-shirts and other print products. Creative and popular designs would be produced by Threadless and sold in the online store, and the designer would be entitled to a share of the turnover. With the help of crowdsourcing, these firms remain active in launching creative new products, and this kind of co-creation business model successfully helps them win the market.

At the dawn of the big data age, the proliferation of concepts such as “cloud data” and “cloud computing” further strengthens the interaction and fusion between Internet users including enterprises and individuals, and hastens the emergence of the new workforce, i.e., the online crowd. Crowdsourcing.org<sup>12</sup> estimates that in 2011, the industry was worth approximately \$750 million and reached roughly \$1.5 billion at the end of 2012, which includes several variations of crowdsourcing such as contest work, ideation, and crowdfunding. This growth reflects the popularity of the workforce model, and how crowdsourcing, especially in

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<sup>11</sup> <https://www.threadless.com/>

<sup>12</sup> <http://www.crowdsourcing.org/>

enterprise use cases, creates a mutually-beneficial relationship that allows enterprises to track work completion in real time, and skilled individuals can complete tasks while connected to the cloud. Therefore, the rise of *crowd in the cloud* might be an inevitable trend that would bring about a revolution in traditional industries, such as education and manufacturing.

As the main arena for achieving competitive advantage in the front end, product conceptualization serves an important platform for the integration of crowdsourcing. The current applications of crowdsourcing take multiple forms such as new idea and innovation creation (Chang et al., 2014a), design contests, problem solving, new product development and marketing, advertising, and brand building (Simula and Ahola, 2014). However, the existing research on crowdsourcing in product conceptualization is scarce, and there is a dearth of systematic and sophisticated crowdsourcing research for product conceptualization. For future crowdsourcing studies, three promising directions for better developing crowdsourcing in product conceptualization for achieving creative design concepts are proposed:

1. *Strategic integration of crowdsourcing into product conceptualization.*

Because of the importance of conceptual design stage and the power of crowdsourcing for assisting PDD, it would be insightful to attempt to integrate crowdsourcing in the product conceptualization phase.

- a. *Macro perspective:* With the emergence of cloud manufacturing, the big picture outlining the big data-supported business chain could be anticipated. Thus, a new product conceptualization mode that

accounts for the potential of cloud computing and relies on collective intelligence is needed.

- b. *Micro perspective*: Product conceptualization consists of some sequential concept development activities.<sup>13</sup> The consistency and smooth connections between these activities/processes are the principal concerns of product design. Therefore, to fully consider the sophisticated concept development process and maximally exploit crowdsourcing, it might be preferable to manageably integrate crowdsourcing into each essential concept development activity (e.g., concept generation, concept evaluation), i.e., to create a holistic crowdsourcing environment for product conceptualization.

2. *In-depth utilization of crowd capital for creativity*. The power of crowd wisdom has been recognized; however, the full potential of crowd capital<sup>14</sup> is still vague. A systematic and profound understanding of how crowd wisdom can benefit product creation is lacking. Therefore, a further discovery of the crowd's competence would be worthwhile, and an in-depth investigation of the role and impacts of crowdsourcing should be considered.

- a. *Embodiment of satisfaction through mass-based creation*: For crowdsourcing, the form of mass-based creation could be a good representation of the crowd's preferences and their personal interests. For product innovation, designers always struggle with the balance between novelty and customers'/users' acceptance. With

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<sup>13</sup> This issue is discussed in Section 2.1.2

<sup>14</sup> See Prpić and Shukla (2013)

the help of crowdsourcing, this dilemma might be properly addressed, since the concepts generated from the crowd could be a referential reflection of the market demand and could ensure a basic market satisfaction and acceptance to some degree.

b. *Proactive market expanding*: Crowd wisdom is actually an extension of “the customers’ voice” in the conventional sense. It provides a new perspective that everyone could be a potential contributor as well as beneficiary. By proactively encouraging increased participation, the interest in the concept development project could be spread among a wider crowd, and the originally indifferent community or non-target-consumers might be stimulated by this interaction mode. Through this kind of co-creation, the leading demands that may drive the market could be found.

3. *Deliberate management of and control over crowdsourcing*. Prior crowdsourcing studies use the basic crowdsourcing scheme (refer to Figure 2.3). The deliberate development of a comprehensive and mature crowdsourcing system is a necessity. Most importantly, the platform establishment and suitable data analysis approaches should be considered.

a. *Platform development*: An adaptable and open platform could support a deeper and wider application of crowdsourcing; therefore, platform development appears to be necessary along with the rising popularity of crowdsourcing. In particular, each element of the basic crowdsourcing scheme (such as how to motivate participants, how to design HITs, and how to control cheating) could be studied

into details. A systematic management strategy for the whole crowdsourcing process is required.

- b. *Data analysis*: The crowdsourced data is often in large numbers; moreover, the data type in product conceptualization may be highly mixed (i.e., numerical, qualitative, and graphical). Therefore, the data analysis methods should be able to i) efficiently deal with a lot of data; ii) handle multiple data types; and iii) accept fuzzy or incomplete data.

## **2.4 Specification of the research problem**

A thorough review of the existing studies in related areas indicated that 1) the current product conceptualization research emphasizes market and consumer-related analysis, and intensive examinations of conceptual design processes are scarce (as identified in Section 2.1); 2) crowd wisdom is acknowledged as a promising innovation source but lacks strategic utilization in product innovation (as identified in Section 2.2); and 3) the potential of crowdsourcing for fostering creativity has yet to be deeply investigated or systematically implemented in product conceptualization (as identified in Section 2.3). The general scope of this study for advancing crowdsourcing studies in order to achieve product innovation in the product conceptualization phase can be outlined as follows.

Primarily, the product conceptualization phase is selected as the main arena (Section 2.1). Compared to prior studies:

- *The focus of this thesis is on design activities (e.g., creating a new concept development environment, facilitating concept generation, evaluation, and*

*selection); therefore, the thesis does not focus on the market-related or customer-centered concerns.*

Once the importance of product innovation for gaining competitiveness is identified (Section 2.2), and the power of crowd wisdom in fostering innovation is recognized (Section 2.3), this thesis intends to exploit crowdsourcing and pursue product innovation.

- *The inputs are crowd wisdom, and the outputs are innovative conceptual designs with improvements on existing similar products.*

However, prior to the strategic application of crowdsourcing in product conceptualization for achieving effective creative conceptual designs, the following challenges have to be overcome.

- *An in-depth employment of crowdsourcing in the conceptualization processes for fostering innovative conceptual designs is scarce. Specifically, a holistic consideration of embedding crowdsourcing into each essential conceptualization activity/process is scarce.*
- *A suitable data processing strategy, particularly for coping with the complex crowdsourced conceptual design information, needs to be explored. In particular, the issues of large crowdsourcing responses, mixed data types, and fuzziness and incompleteness of crowdsourced contributions are consolidated and have not been addressed well.*
- *An investigation strategy into the innovativeness of conceptual product design from multiple perspectives is lacking. Specifically, a constructive definition of “innovativeness of conceptual product design” is missing. An*

innovation evaluation method in the context of conceptual design could be further enhanced.

To address the research gaps summarized here, three main objectives are proposed in this thesis (see Section 1.2).

1. *(In concept generation) Establish a crowdsourcing platform for facilitating the creation of innovative concepts.*
  - a. The innovation target is hierarchically analyzed for outlining the specific requirements for deriving directed and effective participation.
  - b. Human intelligence tasks (HITs) are carefully designed for motivating participation.
  - c. Cheating control concerns are embedded for monitoring participation behaviors
2. *(In concept screening and evaluation) Develop a concept evaluation and selection method in a crowdsourcing environment.* In particular, this method should be able to
  - a. Handle conceptual designs with heavy textual information;
  - b. Unify concept representation to facilitate the quantitative processing of crowdsourced designs; and
  - c. Realize concept selection in a more efficient manner.
3. *(In concept retention) Define the innovativeness of conceptual product design as the main reference for concept retention, and develop an innovativeness estimation strategy.*

- a. Construct the definition of innovativeness of conceptual product design.
- b. Enhance the innovation evaluation system with higher tolerance for fuzzy and uncertain evaluation results.
- c. Develop an estimation algorithm that can cope with fuzzy and uncertain evaluation data.

## Chapter 3 A product conceptualization strategy based on crowd-innovation

The importance of product innovation and the potential of crowdsourcing for fostering creativity have been recognized based on the review of the existing literature in relevant areas. As has been claimed by some researchers, crowdsourcing appears to be promising in soliciting wide resources (including internal and external resources) for improving product competitiveness (Doan et al., 2011; Cook, 2008).

To fully exploit crowdsourcing in product design so as to trigger more effective innovations, the integration of crowdsourcing into product innovation is advocated in this work. Specifically, the concept of “crowd-innovation” is proposed to formulate a creative and sound innovation strategy with which an interaction platform to integrate external and internal resources could be established. The definition of this concept is as follows.

**Definition 3.1:** Crowd-innovation involves merging firms’ internal and external resources through soliciting and fusing the wisdom of distributed crowds and organizations so as to realize a manageable and effective product innovation process with easier access to innovative product concepts.

Thus, the exploration of a novel product conceptualization strategy in this study is based on crowd-innovation; that is, a product conceptualization strategy based on crowd-innovation (PCSCI). As was mentioned in Chapters 1 and 2, it is

worthwhile to strategically integrate crowdsourcing in the product conceptualization phase; therefore, the essential product concept development activities (i.e., concept generation, concept screening and evaluation, and concept retention) are examined separately with regard to the realization of crowd-innovation in each development stage. Three sub-systems are developed to realize the proposed PCSCI, which provides a holistic system that involves multi-faceted knowledge and manages the interrelations among different design stages. Concept generation as a knowledge-intensive concept creation and collection process is studied as the preliminary knowledge acquisition sub-system. Concept screening and evaluation for identifying promising innovative design concepts is studied as the innovation opportunity discovery sub-system. Finally, concept retention, where the current controversial definition of the innovativeness of conceptual product design leads to practical difficulty in retaining innovative concepts, is studied as the innovativeness estimation sub-system.

Specifically, the knowledge acquisition sub-system manages the solicitation of information inputs and might need to: 1) examine related stakeholders/communities as information sources; 2) set up filtering rules to select target contributors; 3) formulate a sound incentive strategy to encourage concept generation; and 4) establish a platform with proper HITs design and sufficient cheating monitoring procedures to transfer, convey, and store the knowledge acquired from the participants. The expected result is a collection of concepts generated and contributed by the target communities.

The innovation opportunity discovery sub-system is intended to identify the promising innovative concepts from the massive ideas contributed by the crowd. Therefore, this sub-system may be required to: 1) extract meaningful information from the knowledge acquisition platform; 2) structure valid knowledge into an unified format for facilitating the subsequent processing; 3) set up a concept clustering process for simplifying the concept comparison; 4) investigate the validity of clustering results; and 5) define selection criteria and establish a decision-making mechanism to identify better concept clusters. Consequently, the promising concept candidates for excellent concepts can be obtained.

The innovativeness estimation sub-system examines the innovativeness of the conceptual designs in order to identify the competitive edge and retain designs with leading advantage. It could be necessary to: 1) outline crucial concerns that might be indicative of innovations; 2) formulate the definition of the innovativeness of conceptual product design; 3) accordingly identify proper criteria to assist in the assessment of design candidates; 4) set up a reliable concept evaluation mechanism fully considering the fuzziness and uncertainty associated with the evaluation results; and 5) construct a robust and consolidated estimation method to process the evaluation data and properly interpret the estimation results. Thus, leading concepts with higher innovativeness will be identified and retained.

In short, this research is assumed to be conducted in the product conceptualization phase and adopt knowledge sources from a distributed crowd with diverse backgrounds. It aims to i) stimulate concept generation and innovation through crowd-innovation; ii) identify better concepts by developing advanced concept

processing and selection methods in a crowdsourcing environment; and iii) identify the innovativeness of leading conceptual designs and retain the competitive edge. To implement the three sub-systems, three parts of work are conducted (as shown in Figure 3.1). They are a web-based knowledge acquisition platform (WKAP) for managing the web- and crowdsourcing-based concept generation and collection; an artificial intelligence-based innovative concept discovery platform (AI-ICDP), which is intended to enhance the selection of innovative concepts in a simplified manner; and a concept learning and retention platform (CLRP), where the innovative edge of leading concepts are recognized and retained. Moreover, these three parts are generally in a sequential order following the concept development flow and are interrelated with one another by providing and accepting concept data to/from one another. Therefore, a complete loop among these three parts is finalized, as shown in Figure 3.1.

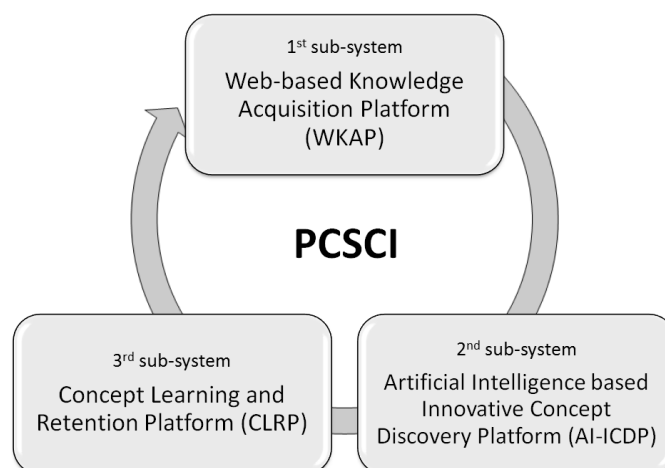


Figure 3.1 Overview of the proposed PCSCI

Section 3.1 provides a brief overview of the research architecture of the proposed PCSCI and presents the crucial sub-systems and key issues in each sub-system.

Sections 3.2 to 3.4 introduce the three sub-systems in order. Finally, Section 3.5 summarizes the chapter.

### 3.1 Overview of the research architecture

Figure 3.2 presents the main processes in each sub-system of PCSCI. The inputs and outputs of each sub-system are also presented. The concepts generated by Internet users from distributed communities are the raw inputs of the proposed PCSCI, while the final yield is a collection of identified innovative concepts. Specifically, the first sub-system, i.e., WKAP, stimulates concept generation and consolidates the collected concepts into a well-organized knowledge base. The second sub-system, i.e., AI-ICDP, selectively extracts concept knowledge from the knowledge base and identifies promising design concepts through deliberate clustering and selection processes. The third sub-system, i.e., CLRP, examines the competitive edge of the better concepts selected by AI-ICDP in terms of innovativeness and retains the concepts with better performance in the knowledge base.

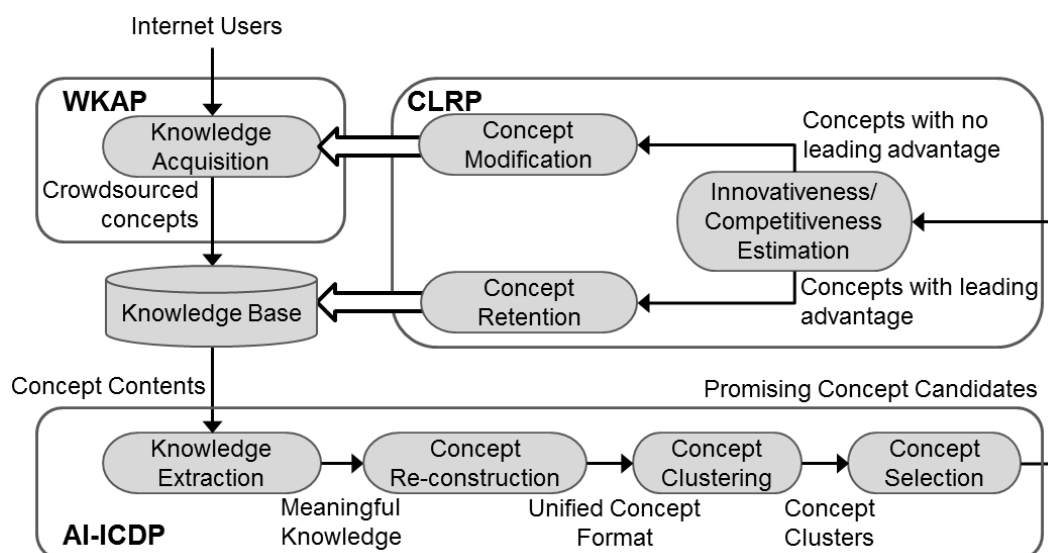


Figure 3.2 Overall research architecture of the proposed PCSCI

WKAP is the initial knowledge acquisition stage of product design and innovation. Especially for crowd-innovation, product concepts are expected to be generated and contributed by external participants and communities. Thus, WKAP is required to bridge the design target and desired contribution and to systematically manage crowd participation and concept collection. In particular, a crowdsourcing interface needs to be provided to connect the participants and project assigners. To encourage the generation of valid concepts, a hierarchical innovation target analysis process should be employed to clarify the specific design requirements that are used as the reference for developing appropriate crowdsourcing tasks. To capture the contributed concepts clearly, a scientific task (HIT) design and allocation method might be required. Moreover, a proper incentive mechanism to stimulate concept generation (e.g., monetary reward, value recognition) should be deployed, and cheating control mechanisms might need to be embedded. Subsequently, the knowledge base is put forward for organizing the collected concepts in order to facilitate the subsequent knowledge processing by AI-ICDP with unified concept representation and structure and for retaining the excellent concepts identified by CLRP so as to provide reference for similar future design problems and to benefit from a continuous concept development and improvement.

Regarding AI-ICDP, four processes are considered to be most important. They are knowledge extraction, concept re-construction, concept clustering, and concept selection. As concepts are normally contributed by Internet users through WKAP (i.e., a Web 2.0-based concept acquisition platform), the knowledge extraction module is required to crawl related web pages and capture useful web contents (which are actually concepts submitted by participants). Considering the complex

and mixed data types involved in conceptual design, the required data type should be defined clearly. Moreover, filtering and pre-processing procedures might be necessary to narrow down the number of concepts (e.g., by removing invalid submissions) and to organize the captured knowledge in a unified format. Given the large number of acquired concepts, a concept clustering procedure is formulated to group similar concepts. In doing so, concept evaluation and selection can be simplified from the comparison of single concepts to the comparison between clusters. This could greatly reduce the concept review workload. To ensure proper concept clustering, a suitable similarity measurement algorithm is crucial and should be formulated carefully. Once concept clusters have been identified, the subsequent process is concept selection, with deliberate considerations especially in setting up clearly-defined criteria and formulating a solid decision-making strategy concerning the multi-attribute and multi-criteria decision situation.

CLRP is intended to provide a way to assess the promising concepts selected by AI-ICDP in terms of innovativeness or competitiveness. For this purpose, a clear definition of the “innovativeness of conceptual product design” or the “competitiveness of conceptual product design” ought to be given. Corresponding criteria to clarify the definition boundaries need to be developed; these criteria also provide important reference for performing the innovativeness evaluation. Once the assessment result in each criterion is obtained, a consolidated estimation algorithm that can handle fuzzy and uncertain data is developed for measuring the overall innovativeness. Thus, a concept ranking related to innovativeness could be achieved. Based on the innovativeness estimation results, the concepts with

leading advantage would be retained in the knowledge base for future development use. Otherwise, the concepts would be considered to be modified or discarded.

## **3.2 WKAP: Web-based knowledge acquisition platform**

### **3.2.1 Introduction**

For WKAP, a primary concern is to establish an online crowdsourcing platform to involve participants and to have basic control over the quality of the acquired knowledge. To realize this purpose, three aspects need to be considered, as shown in Figure 3.3. Firstly, an in-depth analysis of the innovation targets is necessary. The purpose is to drive project assigners to clarify their design requirements completely. By doing so, the project goal could be narrowed down, and the specific requirements in terms of desired participation could be outlined. Moreover, clearer instructions would lead to higher confidence of obtaining valid and valuable contribution. Especially for products with specific use (e.g., sporting goods, maternal goods), the expected contribution might not be from just about anybody but from somebody who has related needs and experience.

Secondly, crowdsourcing is open to the public, which leads to the problem of how to effectively control the participation process without comprising the openness and freedom of idea contribution. To deal with this problem, a deliberate task allocation process is required. By formulating a scientific task design method and a proper task allocation process, it is possible to foster effective responses from participants to the maximum possible extent and to supervise the participation process (e.g., whether participants are inclined to make useful contribution), which

could further increase the rate of desired information. In this respect, some task design principles and guidance are needed, such as ease-of-use, user friendliness, error-free.

Thirdly, due to the anonymous and reward-driven nature of crowdsourcing, cheating is unavoidable. To tackle this problem, relevant task design principles related to cheating control become a must, and a cheating monitoring mechanism might be required to eliminate cheating phenomena and to ensure the basic validity of crowdsourcing responses.

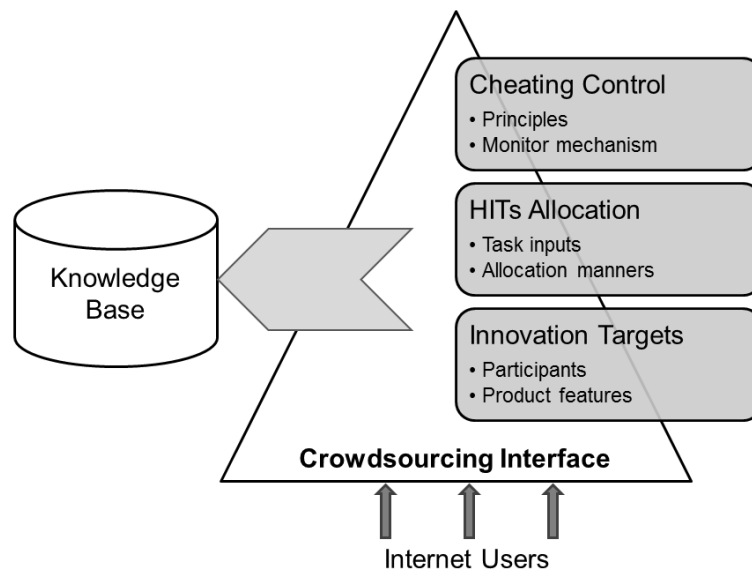


Figure 3.3 Knowledge acquisition

After WKAP, the knowledge base is used to store the acquired design knowledge. A brief description of the formation of the knowledge base is provided. Generally, two domains are defined, as shown in Figure 3.4. One is “Objects” to represent design objects, and the other is “Relations” to represent the connections between these objects. Design objects mainly come from the main components of crowdsourcing, namely, participants, assigners, design projects, and submitted

product concepts. Specifically, the knowledge related to participants such as their gender and income should be recorded. Knowledge related to the design project such as design target and design requirements should also be well-organized to keep track of the complete crowdsourcing project information. Most importantly, the complete knowledge of the contributed conceptual product designs (such as the proposed functions, the attributes, and the specifications) is the analysis target and, therefore, the main source of design objects.

Regarding the relations between design objects, two main perspectives are considered: design relations and semantic relations. Design relations based on design philosophy provide the main reference to connect design objects in order to form a complete design fact. The hierarchical relations in the concept development flow are emphasized, such as the subordinate relations “optional-value-of” and “specification-of”. Using this kind of relations, design objects can be framed into a normal design structure. Semantic relations are vital for textual data. Considering the mixed data types in crowdsourcing, this kind of relations based on textual pattern recognition and textual analysis should also be taken into account. In short, a combination of frame and semantic network is deployed to form the knowledge base.

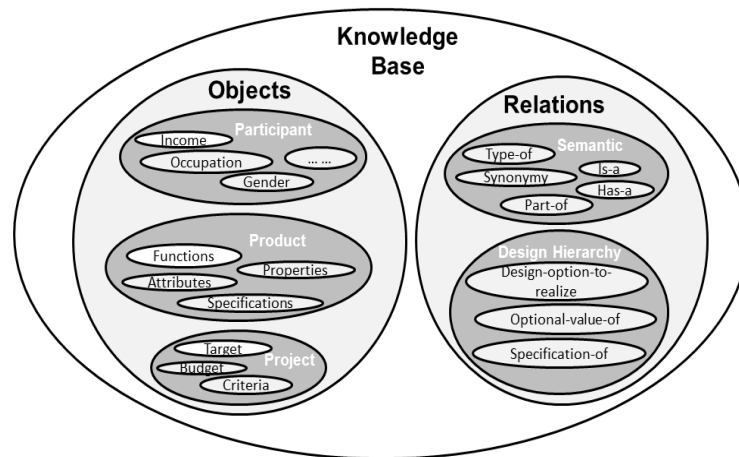


Figure 3.4 Structure of the knowledge base

Overall, ideas are expected to be contributed by the vast network of Internet users. By deliberately setting up knowledge acquisition tasks, control over the participation process could be realized. With the help of a knowledge base, the acquired design concepts are represented in a well-organized structure which facilitates the subsequent processing of the collected concepts.

### 3.2.2 Procedures

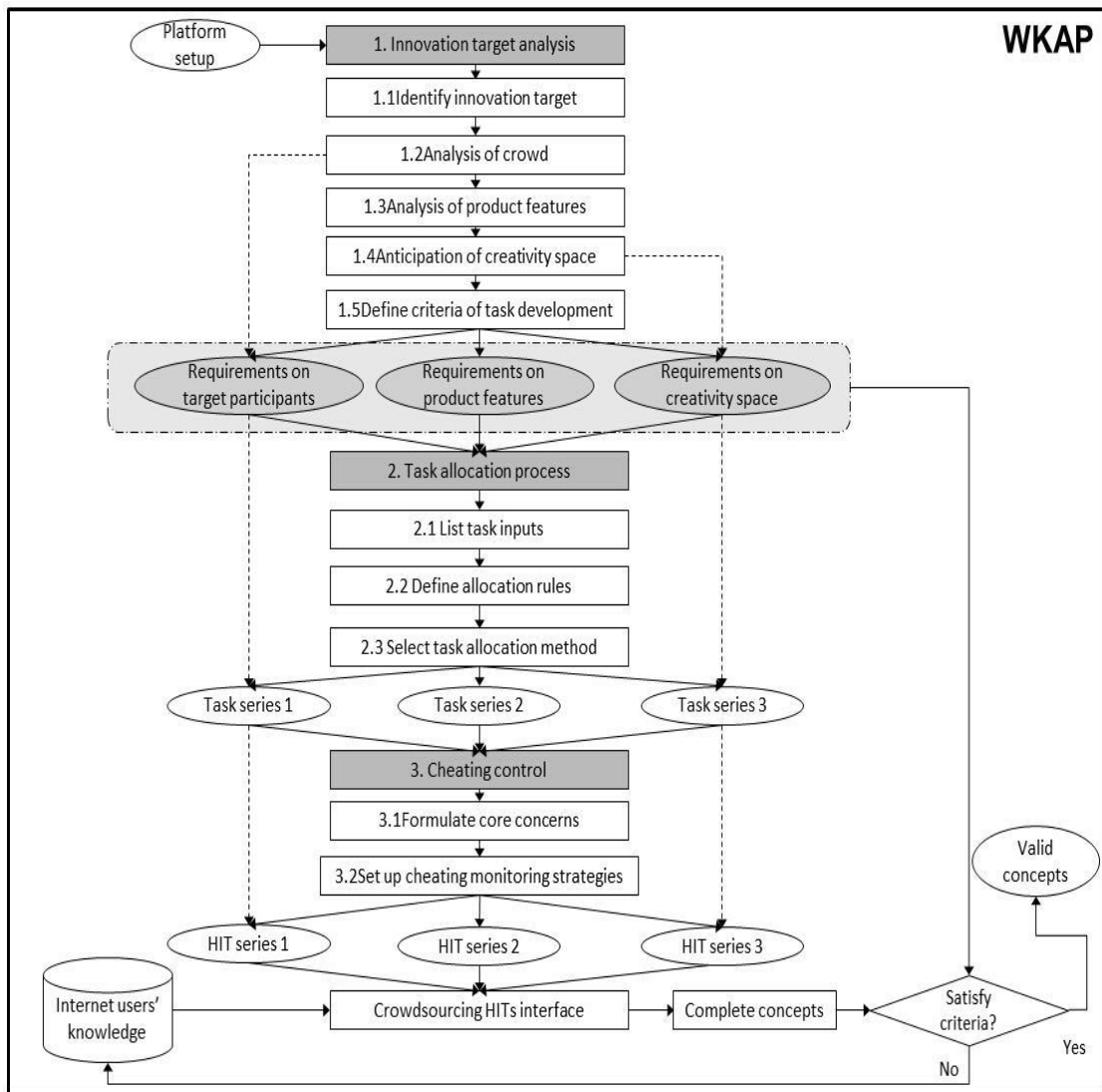


Figure 3.5 Procedures for WKAP

The detailed procedures in WKAP are explained in this section (Figure 3.5).

1. Innovation target analysis to unscramble the overall objective/goal and to convert the tacit expectations to explicit requirements:

*1.1. Identification of innovation target:* e.g., what type of product is studied (market-pull or technology-push), what aspects need to be urgently

improved (appearance or usability), how much change can be accepted (incremental change or disruptive change).

*1.2. Analysis of crowd* to 1) classify possible participants with reference to their background and 2) identify the participants with greater potential to provide valuable contribution.

*1.3. Analysis of product features* to 1) sort out the product details that need to be considered and 2) highlight the aspects on which emphasis should be placed.

*1.4. Anticipation of creativity space* to 1) quantify the expectation or desire of project assigners with regard to certain aspects of the product design and 2) distinguish design requirements in terms of required innovation efforts.

*1.5. Definition of the criteria for task development:* The thorough analysis of the innovation target is summarized and refined into specific requirements related to particular design aspects so as to provide explicit constraints and evaluation standards.

2. Task allocation to set up a proper arrangement of knowledge acquisition tasks keeping in mind the inspiring participants' creativity and to avoid invalid or even hostile participation as much as possible.

*2.1. List task inputs:* The possible task types and their application conditions are summarized to provide evidence for the design and deployment of knowledge acquisition tasks. For example, open questions are useful to elicit relatively complete opinions from participants without the limitation of fixed options.

2.2. *Define task allocation rules*: Based on the criteria obtained from the innovation target analysis, corresponding task allocation rules might be necessary to embody the criteria in the task deployment strategy and to provide practical guidance in task design.

2.3. *Select task allocation method*: Considering the unavoidable intuitive inference in the existing task design activities, greater effort might be required to develop a systematic and reliable task allocation method to identify the most suitable task types or task formats under related criteria.

3. Cheating control to supervise the participation process:

3.1. *Formulate core concerns* that are helpful in eliminating cheating phenomena and improving the participation environment. For example, random answers constitute a common cheating behavior; methods to avoid this behavior should be considered. Moreover, building rapport with participants is important to retain their focus and enthusiasm.

3.2. *Set up cheating monitoring strategies* to address the core concerns identified in the previous procedure. For example, verification questions are recommended to test the qualification of respondents (e.g., whether they possess the required knowledge and skills) and the performance of respondents (e.g., whether their answers are consistent). Similar questions can be repetitively used to test whether the participants are responding randomly. Moreover, questions on sensitive topics that might make respondents uncomfortable should be positioned at the end.

### 3.3 AI-ICDP: Artificial intelligence-based innovative concept discovery platform

#### 3.3.1 Introduction

A progressive filtering process could be a good metaphor for this concept discovery platform as shown in Figure 3.6. The collected crowdsourced concepts are treated as inputs. Through a series of filtering, extraction, and selection, the expected outputs are promising concept candidates. To depict this platform, the main processes and activities are analyzed from the macro and micro perspectives.

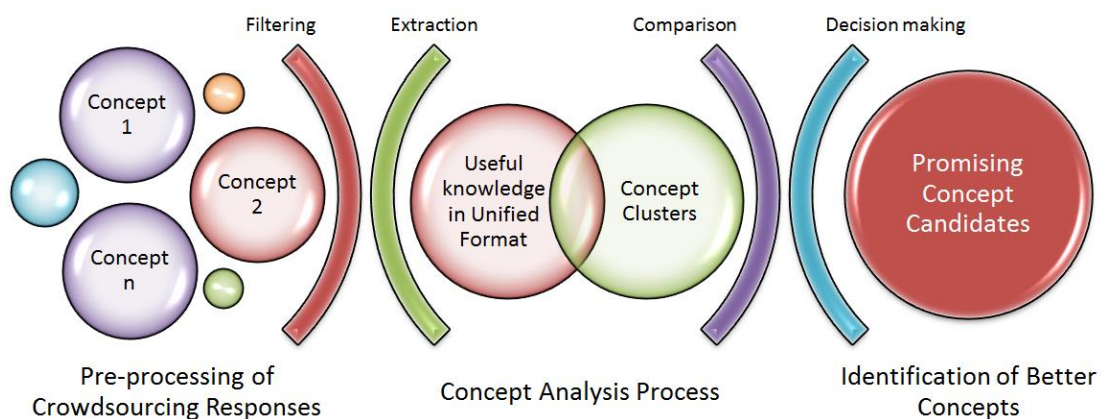


Figure 3.6 Overview of the progressive concept discovery process

From a macro perspective, three processes are deployed. Firstly, the pre-processing of the crowdsourced concepts is necessary. Although the knowledge acquisition platform is established elaborately as discussed in Section 3.2, it is hard to completely eliminate noisy participation (e.g., incomplete submissions, submissions involving identified cheating, shallow responses); therefore, filtering appears to be necessary to remove such invalid submissions. In addition, each design project will have its own requirements with regard to valid participation (e.g., word limit, design focus), which add further concerns related to concept filtering. After a preliminary screening of the qualified concepts, a knowledge

extraction procedure is deployed to extract useful information from the online knowledge acquisition platform. The extraction method should be able to capture the web content and deal with pre-specified data types. Secondly, a concept analysis process is used for the detailed processing and evaluation of the extracted concepts. To facilitate the analysis procedures, the extracted concepts are constructed into a unified format, which facilitates comparison. To further simplify concept evaluation and comparison, a clustering procedure is employed to group similar concepts and narrow down the comparison from individual concepts to concept clusters. Thirdly, a process for identifying better concepts is deployed, in which the key issue is to select a proper decision-making strategy. In doing so, the concepts with a better general performance in all the design criteria are identified as promising concept candidates and treated as important reference concepts for further development.

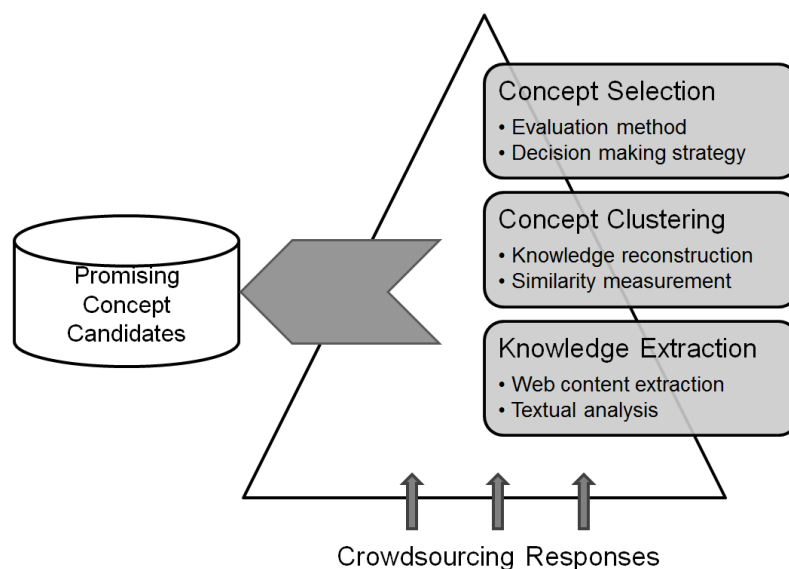


Figure 3.7 Main concerns in realizing AI-ICDP

From a micro perspective, some detailed concerns are investigated (Figure 3.7). Knowledge extraction is inclined to web content extraction, since the concepts are

collected through WKAP (an online platform). The capability of crawling web pages and capturing web content is needed. Moreover, design concepts are often presented in the form of textual descriptions and graphical models. This indicates that textual analysis might be necessary. Textual pattern recognition, meaningful information retrieval, and tokenization could help in the preliminary processing of the extracted rough document elements. For concept clustering, concept reconstruction is considered to improve the comparability of crowdsourced concepts by structuring them into a unified format. To realize a reliable restructuring, design principles from the design perspective and semantic concerns from the document analysis perspective should be jointly considered. With the integration of these concerns, similarity measurement should be improved, and corresponding measurement algorithms should be properly selected. Specifically, from the design perspective, similarity could be studied using the hierarchical relations in the concept development flow, and from the semantics perspective, the cosine function could be a good option to examine the literal similarity. For concept selection, the primary concern is to identify an evaluation method, which actually involves quantifying the assessment results. In this process, the pre-specified design requirements provide the evaluation criteria. To improve the reliability of concept evaluation, the criteria could be broken down into more detailed items, and a reference concept could be introduced to support the judgment. Based on the evaluation results, a decision-making strategy is needed to identify the promising concept candidates. Except for the design criteria, the factors that may impact the final decision (e.g., weight/priority of each criterion,

the influence of different evaluators, the index of different time periods) should be taken into account.

In general, this platform is knowledge-intensive; therefore, reliable knowledge processing methods or data analysis techniques are required. As mentioned in Chapters 1 and 2, an in-depth exploration of a suitable data processing strategy specifically intended for coping with the complex crowdsourced conceptual design is lacking. Considering the large amount of crowdsourced data and mixed data types, artificial intelligence (AI), which covers various powerful machine learning and data processing techniques (e.g., neural network, data mining), is considered to provide the required quantitative support. Therefore, this platform is an AI-support platform.

### 3.3.2 Procedures

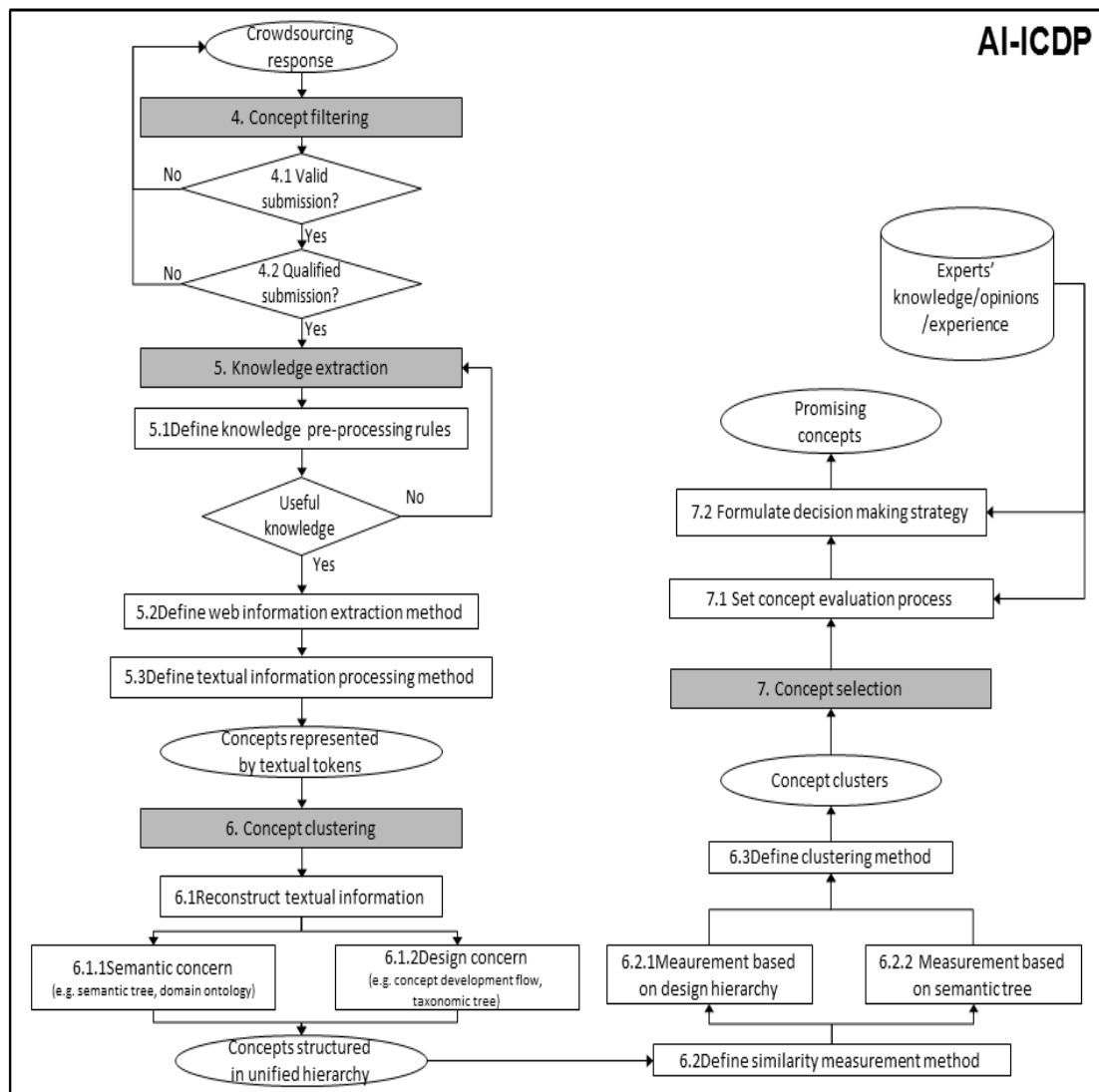


Figure 3.8 Procedures for AI-ICDP

The detailed procedures to realize the discovery of promising concepts are as follows (Figure 3.8):

4. Concept filtering to perform a preliminary screening of the crowdsourcing submissions:

*4.1. Remove invalid submissions:* This step is meant to eliminate noisy data.

For example, incomplete submissions will not be considered for the

subsequent processing. In addition, the identified cheating submissions are directly removed.

4.2. *Remove unqualified submissions*: This is an additional filtering step based on extra requirements. For example, some projects may have a word limit; therefore, very shallow submissions containing very little information would be treated as useless responses, although they are complete. If one design project focuses on PC keyboard, submissions with heavy descriptions of PC design but little focus on keyboard would be disqualified. Thus, this step roughly selects the qualified concepts that could be considered for further analysis.

5. Knowledge extraction to extract useful information from the crowdsourcing platform:

5.1. *Define knowledge pre-processing rules*: Normally, the knowledge contributed by the crowdsourced design concepts is inconsistent. The concepts could be in different lengths, and the different lengths may contain different amounts of design information. The presentation format of the design concepts may also be very different. Some concepts may be presented in graphic models, and others may be explained mainly in text. Therefore, a pre-processing of the diverse responses might be necessary to identify relatively useful knowledge.

5.2. *Define web information extraction method*: To deal with the concepts collected through the online platform, proper web information handling methods are needed. In this regard, the issues of 1) what kind of information should be extracted, 2) what technique should be applied,

and 3) how to set the strategy to realize information extraction should be considered.

5.3. *Define textual information processing method*: To better present and explain the conceptual design, textual information or illustration is unavoidable. This indicates that the ability to specially deal with textual/linguistic information is required. A proper method could increase efficiency in handling textual information.

6. Concept clustering to classify similar concepts in order to facilitate comparison among and selection from these concepts:

6.1. *Reconstruct textual information* in order to reach a unified format of crowdsourced concepts. This step is meant to prepare for the subsequent procedures, since a unified structure could greatly facilitate concept comparison and simplify the subsequent processing.

6.2. *Define the similarity measurement method*: Specifically, the distance between different design concepts (e.g., in terms of semantic meaning) is expected to be clearly defined, and proper distance formula (e.g., Euclidean distance or cosine distance) should be selected. This procedure is mainly intended to tailor similarity measurement for targeted research needs.

6.3. *Define the clustering method* to determine a suitable classification system for clustering similar concepts. The classification is based on the preceding similarity measurement.

7. Decision-making and concept selection to identify the promising concept candidates:

7.1. *Set concept evaluation process*: The core concern is to identify a proper concept evaluation method. The incorporation of the designers'/experts' knowledge is unavoidable; therefore, how to improve the reliability of concept evaluation deserves exploration.

7.2. *Formulate a decision-making strategy* by including concerns about 1) the comparison of the clusters; 2) the identification of the cluster with better general design quality; 3) the weighing of different comparison aspects; 4) the influence caused by different decision makers; and finally 5) the consolidation of these concerns in order to reach a comprehensive decision.

## **3.4 CLRP: Concept Learning and Retention Platform**

### **3.4.1 Introduction**

For concept retention, the primary concern is to set the standard in order to verify which concepts deserve to be retained for future use. Among the various standards (e.g., design quality, competitiveness, and cost-benefit), this study focuses on innovativeness, which reflects the quality of being novel, the ability to introduce new ideas, and the degree of innovation. Often, it could be replaceable with novelty, newness, and originality. However, how to properly define and estimate the innovativeness of conceptual product design (ICPD) is currently controversial (as discussed in Chapters 1 and 2), which indicates that the initial research on CLRP might require exploration for an improved approach for defining and estimating innovativeness. As such, a grey-and-fuzzy-based concept innovativeness estimation approach (GF-CIEA) is emphasized in this study.

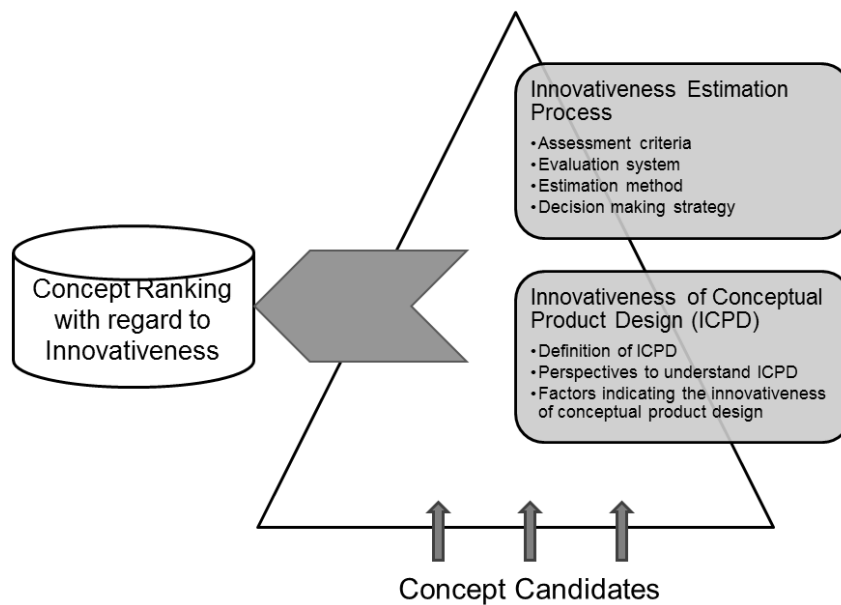


Figure 3.9 Overview of GF-CIEA

Generally, the identified promising concept candidates are the inputs of this platform. By estimating the concept innovativeness, the concept candidates are further verified, and a concept ranking with regard to their innovativeness is expected to provide the reference for concept retention. Specifically, the definition of ICPD is investigated. By its nature, “innovativeness” cannot be discussed separately from the study focus and context. This suggests that a universal standard or threshold does not exist to verify innovativeness. A widely accepted view is that innovativeness has 1) multiple perspectives, 2) multiple attributes, and 3) multiple determinants. Conceptual product designs are characterized by limited information, tacit knowledge, and ambiguous/vague expressions, to name just a few. Such characteristics in effect lead to practical difficulties in the assessment of these designs (e.g., the bias in understanding and prospect theory). With regard to these issues, multiple perspectives to understand and define ICPD appear to be badly needed. Based on a comprehensive and structured definition, the assessment could

be more directed and evidential. From each perspective, the significant innovation-related factors are listed as the determinants for measuring ICPD. Further, these factors can be decomposed into more detailed items to provide sufficient details to help differentiate the conceptual designs and to make a reliable assessment.

Moreover, the multiple perspectives and hierarchically decomposed determinants could offer the best reference for setting up the assessment criteria. The innovativeness estimation process is subsequently executed under these criteria. In this process, the crucial concern is to develop suitable methods or algorithms for the procedures of evaluation, estimation, and decision-making. In particular, the fuzziness, bias, and uncertainty involved in the evaluation procedure should be carefully studied. Among the existing evaluation methods, the rating scale is popular and commonly adopted. The two main types of rating scale are the ordinal scale, which simply tests the evaluation attitude on each rating level, and the interval scale, which reflects the meaning of the distance between different scores but cannot accept an uncertain input (i.e., the rating score should be a definite number). Thus, an improved evaluation method that can accept fuzzy and uncertain inputs is needed. The ability to handle fuzzy and uncertain data is also necessary for the estimation algorithm. This study focuses on fuzzy theory (which is especially useful for processing fuzzy data) and grey theory (which is powerful in coping with uncertain data) and uses them as the technical base for constructing the estimation algorithm. Finally, the decision of which concepts deserved to be retained should be made. In this procedure, a threshold might be set to assist the judgment. Moreover, the weighting, indexing or prioritizing concerns might be selectively incorporated.

### 3.4.2 Procedures

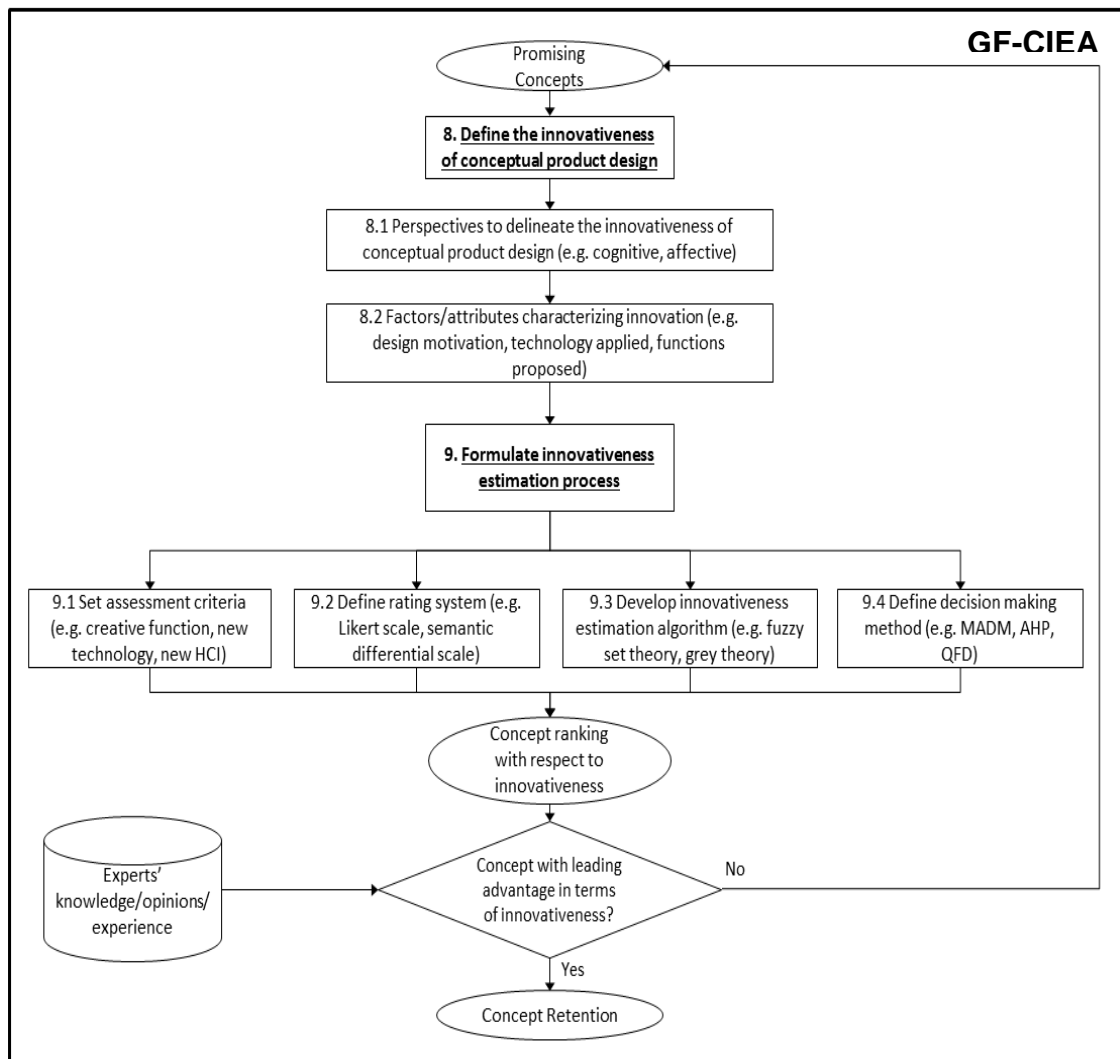


Figure 3.10 Procedures for GF-CIEA

The detailed procedures deployed to formulate GF-CIEA are as follows (Figure 3.10):

8. Define the innovativeness of conceptual product design through a multi-perspective view:

*8.1. Identify the perspectives to delineate ICPD:* Practically, the understanding of ICPD heavily depends on the firms' competence and

the evaluators' knowledge and experience. In other words, a product that is new compared to existing products or a product that is new in relation to the evaluators' previous experience is more likely to be defined as innovation in practice. Therefore, ICPD could be examined from two perspectives: the cognitive perspective (innovativeness referring to some objective benchmarks) and the affective perspective (innovativeness with reference to evaluators' emotional effect). The deployment of these two perspectives is actually a strategy to realize the control over the personal bias by allowing a special test of the evaluators' attitude and the emotions underlying their evaluations.

8.2. *List important factors/attributes characterizing innovation*: This step is meant to identify the factors that could indicate the innovativeness of product designs from each perspective, so as to establish a more explicit outline of ICPD. For example, creative functions, innovative technologies, and new human computer interaction (HCI) are embodiments of ICPD, which could help to concretize the definition of ICPD.

9. Formulate innovativeness estimation process:

9.1. *Set the assessment criteria*: Based on the factors identified in Procedure 8.2, the relevant criteria could be generated. Further, each factor could be broken down into more detailed items in order to offer sufficient details to reach a more reliable judgment. In addition, reference concepts could be introduced to further clarify the criteria.

9.2. *Define the rating system* for collecting and quantifying the evaluation results. Generally, the acceptable rating should be a crisp number (representing the assessment level or score), which may restrict the freedom of evaluators to assign any score they want. Therefore, an improved assessment system that enables fuzzy or uncertain inputs is highly desirable.

9.3. *Develop an innovativeness estimation algorithm* that can cope with the fuzzy and uncertain rating scores. Fuzzy sets theory (for dealing with fuzzy numbers) and grey theory (for handling uncertain grey numbers) are highlighted.

9.4. *Define the decision-making method*: A decision-making strategy—e.g., multi-attribute decision making (MADM), Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD)—should be deployed in this step. The relevant concerns such as 1) how to weight different criteria and 2) how to set the threshold for making the selection should be jointly studied.

### **3.5 Chapter summary**

A product conceptualization strategy based on crowd-innovation (PCSCI) is presented in this chapter. The concept of “crowd-innovation” is proposed to encourage the seamless incorporation of crowd wisdom in the product conceptualization phase in order to achieve better creative ideas. In some sense, it advocates the fusion of internal and external resources. By expanding the available

knowledge sources to encompass wider communities, an innovation-driving conceptualization environment could be created.

Given some of the problems identified in the Literature Review Chapter, an in-depth integration of crowdsourcing is formulated to establish a holistic crowdsourcing environment for concept development activities. Three sub-systems are developed, each of which focus on one essential conceptualization process, i.e., concept generation, concept evaluation and selection, and concept retention. Moreover, corresponding data analysis strategies are developed for each sub-system. On the one hand, the data processing methods are required for handling the crowdsourced conceptual designs. On the other hand, they should enable the data transfer between different sub-systems so as to support the interrelations among these design activities.

The first sub-system, i.e., WKAP, is developed to realize a crowdsourcing-based concept generation platform. To ensure manageable knowledge acquisition from distributed crowds, a sophisticated exploration into how to motivate participation, how to foster more effective contributions, and how to control cheating behaviors is performed. Specifically, an innovation target re-analysis process is deployed to ensure explicit participation instructions. A novel HIT design and allocation process is developed to derive effective responses by building rapport with participants via suitable and comfortable task assignment. In addition, a participation monitoring mechanism is built on the cheating control concerns/principles to further assist in achieving high-quality contributions.

The second sub-system, i.e., AI-ICDP, is developed to identify promising concepts from the crowdsourced ideas selected by WKAP. A knowledge extraction process is deployed to extract the design concepts submitted to the online platform; therefore, the capabilities of capturing web contents and handling textual information are necessary. Subsequently, a concept clustering process is designed. This process is intended to group similar concepts so as to simplify concept evaluation and comparison. For this purpose, a concept reconstruction process is formulated to organize the submitted designs into a unified format. Moreover, an improved similarity algorithm is developed to provide a more reliable concept similarity measurement. Based on the concept clusters, a concept selection process is deployed. Using deliberate evaluation matrix, the overall quality of the concept clusters could be measured, and better clusters with promising concept candidates could be identified.

The third sub-system, i.e., CIRP, is proposed to further verify the promising concepts selected by AI-ICDP in terms of their innovativeness. An innovativeness estimation approach, i.e., GF-CIEA, is specifically developed to define and measure the innovativeness of conceptual product design (ICPD). Primarily, an intensive investigation into the definition of ICPD is conducted. Based on a multi-perspective understanding, the factors/attributes/determinants that could influence innovativeness are generated. Considering the fuzziness and uncertainty involved in the evaluation process, fuzzy logic and grey theory are emphatically utilized to aid in the innovativeness estimation. Based on the estimation results, the concepts with leading advantage could be identified and considered for concept retention.

The detailed implementation of these three sub-systems is presented sequentially in Chapters 4, 5, and 6.

# **Chapter 4 Sub-system 1 (WKAP): A crowdsourcing platform development approach based on fuzzy neuro-network**

## **4.1 Introduction**

As described in Chapter 3, WKAP is a primary sub-system of the proposed PCSCI. To set up this knowledge acquisition platform, a crowdsourcing platform development approach is proposed. The review of the existing literature revealed that most of the existing crowdsourcing applications remain at the general embedding of the conventional crowdsourcing scheme (i.e., post the target project online without deliberate design and wait for participants to contribute in exchange for monetary compensation). That is, a crowdsourcing system with a systematic or unified framework for supporting product innovation has yet to be well addressed. Therefore, it is worthwhile to develop an elaborate crowdsourcing system and build a systematic crowdsourcing platform development approach.

Corresponding to the main elements of crowdsourcing identified in Section 2.3, such an approach is proposed to deal with the following concerns:

1. *Innovation target re-analysis*: As a directed/participative crowd integration strategy, crowdsourcing is supposed to give clear instructions in order to direct participation with guaranteed quality. However, this is often neglected in crowdsourcing practices. Hence, a hierarchical target decomposition process is

required to induce project assigners to give more explicit instructions and requirements.

2. *HITs design and allocation*: The typical task arrangement in crowdsourcing projects is random and lacks careful design. Thus, it is imperative to establish an effective quantitative method to support the design of crowdsourcing tasks.
3. *Cheating control*: Few anti-cheating concerns have been embedded in the initial stage of task design. Therefore, cheating monitoring measures are considered to further improve the quality of crowdsourcing responses.

Based on this understanding, the proposed prototype sub-system emphasizes three cohesively interacting modules, namely, an innovation target analysis module, an innovation-oriented HIT allocation module, and a cheating control module. A case study on future PC design has been used to illustrate and demonstrate this system.

## **4.2 Specification of research gaps**

As mentioned in Chapter 2, there have been several crowdsourcing-related studies in recent years. Poetz and Schreier (2012) conducted a study in which crowd workers showed stronger power to create innovative ideas. Regarding task design methods, Khasraghi and Mohammadi (2012) reported that crowdsourcing tasks should be distributed based on the crowd workers' interests and skills. In addition, the tasks can be designed using Computer-Aided Design (CAD)/Computer-Aided Manufacturing (CAM) (2D or 3D) to capture the participants' cognitive activities (Corney et al. 2010b). With regard to the issue of cheating, some attempted to detect cheating by organizing preference testing (Buchholz and Latorre, 2011), calculating the reputation rank of participants (Allahbakhsh et al. 2012), and

investigating the relationship between the “meaningfulness” of a task and the workers’ effort (Chandler and Kapelner, 2013). Considering the potential of crowdsourcing in supporting the creation of innovative concepts and emerging research efforts in enhancing crowdsourcing methods, a unified and improved crowdsourcing system that systematically integrates the concerns of task design and cheating could lead to more chances for effective product innovation (Doan et al. 2011; Cook, 2008).

Although the potential of crowdsourcing for creativity has been identified, gaps remain in the development of crowdsourcing for supporting product innovation. The main problems that need to be overcome are:

1. *Scarcity of effective crowdsourcing schemes to support product innovation:*

Crowdsourcing is an important method for recruiting a large number of workers. However, a typical scheme of crowdsourcing simply provides a general outline of the connections among employers, Internet platforms, and online workers. The concerns, especially related to supporting product innovation, are few.

2. *Lack of a systematic method to assist the design of crowdsourcing tasks:*

Referring to existing crowdsourcing projects, HITs are often designed according to the instructions of the crowdsourcing platform. However, the question types provided by these platforms are fixed, and the limited question types may lead to the employers’ negligence in the task allocation process. According to the theory and principles of questionnaire design (Krosnick and Presser, 2010), the question type and order have significant impacts on the

survey results. Product innovation encourages participants to think and create freely. To stimulate innovative ideas, crowdsourcing tasks should have the necessary openness to absorb diverse ideas, reasonable complexity to control participants' burden, and scientific order to retain respondents' attention. Therefore, task design deserves further exploration and should be deliberately handled.

3. *Lack of a mechanism to control cheating in crowdsourcing:* Because of the anonymous nature of crowdsourcing, it is hard to guarantee the motivation and qualifications of the crowd workers, and there is a risk of cheating. Cheaters can be broadly defined as respondents who do not meet the task requirements (e.g., those who do not follow instructions). There are clear incentives for workers to cheat: reward, duration, and recreation. Most of the online workers are attracted by the monetary rewards. To get these rewards, they would want to complete as many tasks as possible, which could result in cheating. Moreover, every project posted on crowdsourcing platforms has a fixed duration. Under time pressure, workers may rush to complete the tasks and sacrifice the quality of their response. Finally, some participants treat the crowdsourcing tasks as recreation and tend to cheat.

The proposed sub-system is expected to tackle these issues in order to enhance the crowdsourcing effects and support the creation of innovative concepts.

### **4.3 System architecture**

A framework of the proposed crowdsourcing system is presented in this section (Figure 4.1). Based on a typical crowdsourcing scheme, the process for developing

crowdsourcing tasks is emphasized in this study. A crowdsourcing task development mechanism was established to bridge the gap between the project requirements and the specific crowdsourcing tasks. This mechanism mainly consists of an innovation target analysis module, an innovation-oriented HIT allocation module, and a cheating control module. The innovation target analysis module is developed to deeply analyze the project requirements and decompose the general target into specific innovation requirements on the participants, product features, and creativity space. Based on the particular requirements, an innovation-oriented HIT allocation module is developed to assign suitable tasks. Finally, a cheating control module is constructed to enhance the task design by formulating anti-cheating strategies at the initial stage of task design.

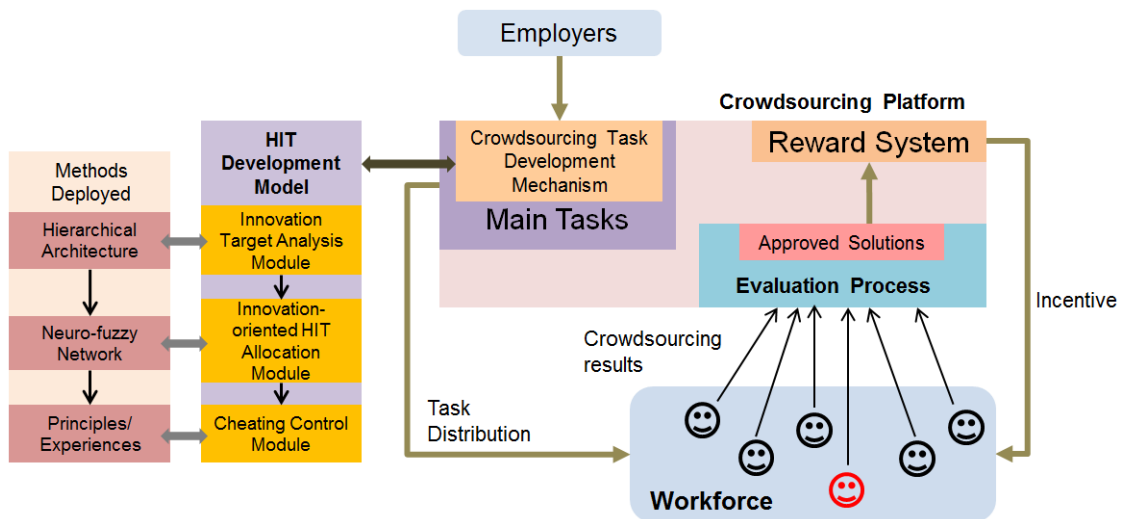


Figure 4.1 Overall framework of the proposed crowdsourcing system

Conventional crowdsourcing is generated directly by the developers according to project requirements and lacks sufficient consideration of a reliable quantitative model to identify suitable tasks. Therefore, a task development model is needed to improve the task development process (Figure 4.2). In general, the innovation

target analysis module aims to identify the target participants, determine the product features to be designed, and estimate the allowed space for creativity (e.g. incremental or radical change). The innovation-oriented HIT allocation module is a quantitative process to find the most suitable tasks that can best serve the creation and collection of innovative concepts (e.g., acquisition of novel designs). To improve the effectiveness of crowdsourcing, a cheating control module with a set of measures and principles is formulated in the task design stage.

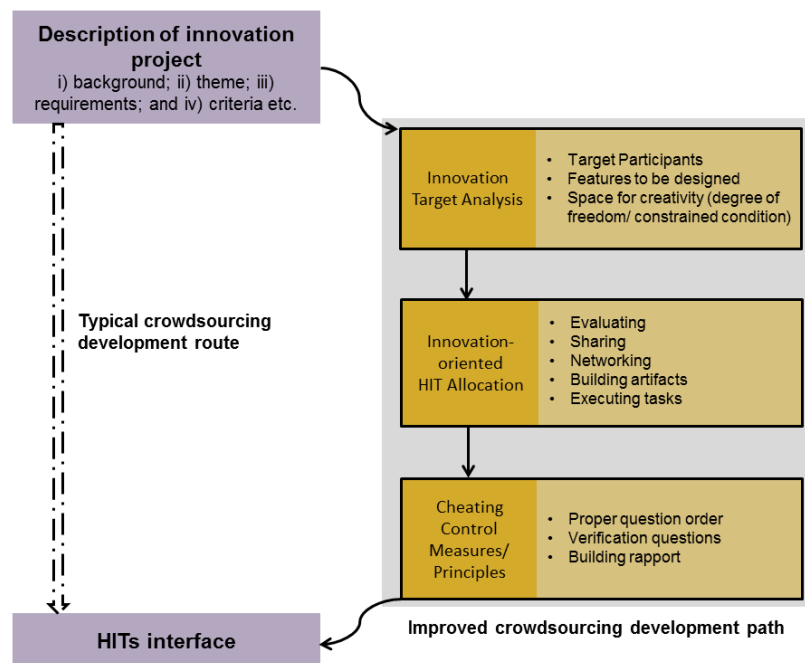


Figure 4.2 Task development process

### 4.3.1 Innovation target analysis

To decompose the innovation goal hierarchically and organize these features systematically, a hierarchical architecture is established, as shown in Figure 4.3. Overall, the innovation goal is analyzed from the following aspects: target participants, product features, and creativity space. In every aspect, specific dimensions/features are derived. Products in different categories may have very

different features to be considered. This architecture is an attempt to formulate a strategy of how to decompose an innovation project into well-organized product features. The very specific features or dimensions need to be identified according to the requirements of different projects.

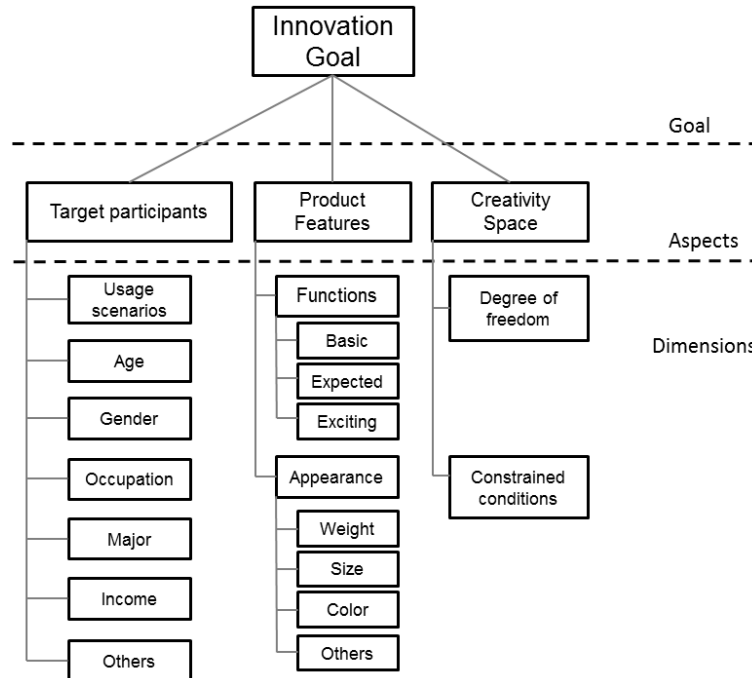


Figure 4.3 Hierarchical structure of target analysis module

- **Target participants**

The large number of online workers is the major advantage of crowdsourcing. However, more participants do not necessarily lead to better ideas. To make matters worse, there could be more noisy and chaotic data. In this sense, the “crowd” should refer to valid participation rather than the number of participants. Considering the success factor of conventional product innovation approaches (e.g., focus group and face-to-face interviews), the participants’ qualifications need to be

carefully investigated, which indicates that the selection of qualified participants needs to be a critical concern of crowdsourcing.

The target participants should be identified according to the project requirements. For customer-oriented products, it is preferred that the participants are end-users. For example, to design an innovative baby feeding method, it is appropriate to invite mothers to participate. For technology-oriented products, participants with a professional background or relevant knowledge are preferred. For instance, mechanical engineers are the target participants for the innovation of mapping devices for a lathe. Generally, this procedure involves the screening of suitable participants so as to ensure effective responses.

- ***Features to be designed***

The deployment of crowdsourcing tasks relies heavily on what product features are needed and how much space for creativity is allowed. It is strongly recommended that a clear feature list should be provided, which can provide the foundation for developing crowdsourcing tasks. By following the hierarchical structure of the features to be designed, the process of assigning crowdsourcing tasks can be made more manageable and systematic. Moreover, it is better to list the product features in order to avoid missing any specific customer requirements (Kwong and Wong, 2008).

- ***Space for creativity***

For different innovation projects, the assigners have different expectations about the degree of innovativeness (e.g. incremental improvement or radical invention).

Hence, the concept of “*space for creativity*” is proposed in this work and is defined through two parameters: “*degree of innovation freedom (DoIF)*” and “*constrained conditions*”.

*Degree of innovation freedom*: This parameter is used to measure how much these features are expected to be improved and how freely they can be innovated. For example, if the appearance (e.g. size, shape, color) has a DoIF of 100% while the function design has a limited DoIF (<100%), it would indicate that the employers are more concerned about appearance design than function design.

*Constrained conditions*: This parameter is used to identify the features that do not need to be changed. For example, the basic configuration of a computer should be fixed, and the innovation directions may be hidden in human computer interaction, interface design or new applications.

Through the innovation target analysis module, the features to be designed are organized in an orderly manner, and they are classified into innovation-free features and constrained features. Thus, it not only provides assistance to participants to innovate in a more effective way but also increases the opportunities for obtaining valuable ideas.

### **4.3.2 Innovation-oriented HIT allocation**

To support the creation of innovative ideas, proper HITs need to be identified to capture the participants’ ideas and inspirations. In this section, the task allocation process is explained using i) examples of crowdsourcing task inputs and ii) a neuro-fuzzy task allocation method.

#### ***4.3.2.1 Examples of crowdsourcing task inputs***

According to Doan et al. (2011), the contributions that users can make are limited in many crowdsourcing systems. The basic task types include evaluating, sharing, networking, building artifacts, and executing tasks, to name a few. To implement these task types, some specific task inputs are generated. For existing crowdsourcing platforms, the common task inputs include single/multiple choice questions, scale, slider, and text. These task inputs can be roughly analyzed according to their openness and complexity.

Single/multiple choice questions are popular tasks, as they provide clear options for the respondents to choose from, and the operation is simple enough. These questions are suitable for collecting information about constrained features that do not need too much innovation. Scale and slider are relatively difficult compared to single choice questions, as the respondents need to deliberate in order to give a proper rating or percentage. The operations for completing scale or slider questions are not very complex, and the answers are restricted within a range so as to reduce the participants' burden. Normally, they are used to capture the participants' preferences and perform evaluation on the design alternatives. There is another question type, i.e., sequencing, which is useful for the comparison and evaluation of different items. Compared to scale and slider, sequencing problems require more actions (e.g., selecting, sequencing, and adjusting), and more attention is required for such questions. Blank filling and text insertion are often used in open questions to solicit original answers from respondents. With regard to operations, more effort is required, and more time is needed to generate proper words. Therefore, the blank filling/text questions should be arranged in such a way as to

acquire original ideas from participants, and should not appear too frequently in one crowdsourcing project.

Table 4.1 presents the main tasks that have been popularly used by existing crowdsourcing platforms, organized by ranking. This ranking takes into account the openness of questions and the complexity of operations; therefore, this ranking could represent the comprehensive difficulty in considering the aspects discussed earlier.

Table 4.1 List of crowdsourcing tasks

<b>Task Level</b>	<b>Tasks</b>	<b>Task Level</b>	<b>Tasks</b>
VL	Single choice (from checkbox)	RL	Grid scale
L	Single choice (vote)	RL	Single slider
L	Evaluation through single choice	RL	Grid multiple choice
L	Classification through single choice	M	Evaluation through slider
L	Single choice (from drop-down list)	M	Single weighting with slider
L	Single scale	M	Grid multiple choice (with categories)
L	Multiple choice (from check box)	M	Multiple choice (combine Text)
L	Multiple choice (vote)	M	Grid slider
L	Single number entry	RH	Grid number entry
L	Evaluation through multiple choice	RH	Grid weighting slider
L	Classification through multiple choice	RH	Grid text entry
RL	Grid single choice	H	Sequencing
RL	Grid single choice (with categories)	VH	Upload
RL	Simple words entry	VH	Paragraph text
RL	Single choice (combine Text)		

(VL=very low, L=low, RL=rather low, M=medium, RH=rather high, H=high, VH=very high)

#### ***4.3.2.2 A neuro-fuzzy task allocation method***

In this study, a neuro-fuzzy approach is developed to assist with the task allocation.

Considering the inputs (viz. the product features to be designed) and the output

(viz. suitable task level), they are often described using linguistic terms such as “very complex” or “highly difficult.” To deal with the qualitative descriptions, fuzzy methods are adopted as the most suitable way for dealing with linguistic variables. The method is depicted in Figure 4.4, which mainly involves four layers, namely, the layer of crisp inputs, the layer of fuzzification, the layer of fuzzy rule base, and the layer of defuzzification.

The linguistic terms/variables form the fuzzy sets. The layer of crisp inputs is intended to transform the fuzzy sets into crisp numbers that can be processed by membership functions. The fuzzification layer involves the process of transforming the crisp inputs into membership degrees. For this layer, the key point is to define proper membership functions. According to the membership degree, fuzzy rules provide the reasoning evidence to derive the results under different conditions. At this stage, the establishment of the rule base should comprehensively consider related research, expertise, and existing publications in order to achieve reliable fuzzy rules. Finally, the defuzzification layer integrates the results of the fuzzy rules and quantifies the results into a numerical format.

Regarding the task design, the type of task is the primary concern. Generally, tasks can be classified into open and closed questions (Taylor-Powell, 1996; Leung, 2001). Given the demands of an innovation project, the openness of tasks should be deliberately determined to stimulate the respondents' creativity. Task difficulty, respondent's ability, and respondent's motivation are three major factors in questionnaire design (Krosnick, 1991; Krosnick and Presser, 2010). This leads to awareness in HIT design to set the operations with proper complexity and to fully

account for the need for cognition. In this regard, Rampino (2011) highlighted the importance of participants' cognitive abilities and emotional reactions. Based on the analysis, the inputs are decomposed into three dimensions that represent the most crucial concerns of task design: i) *the degree of innovation freedom*, which is related to the openness of the task for acquiring innovative opinions from participants, ii) *human input in terms of operations*, which considers the complexity of operations to complete the task, and iii) *human input in terms of attention*, which reveals the cognitive ability and seriousness required for this task. Therefore, every feature can be defined through three dimensions that are denoted as “*degree of freedom, required human input in terms of operation, required human input in terms of attention.*”

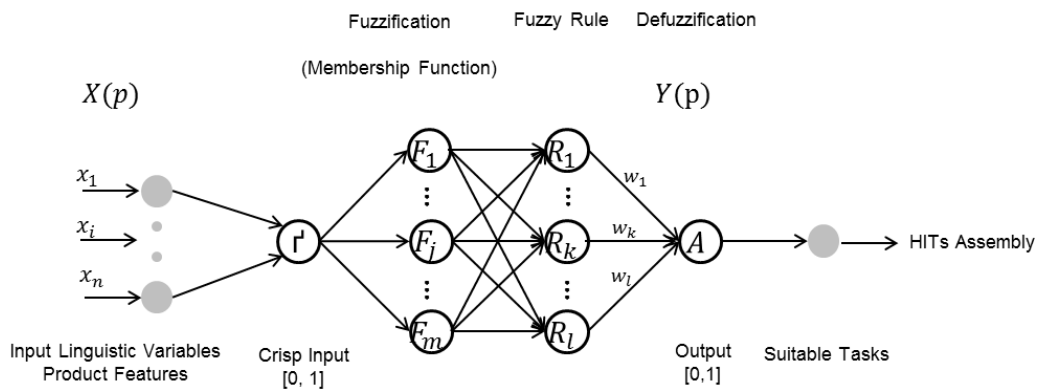


Figure 4.4 Task Allocation Method – A neuro-fuzzy network (Negnevitsky, 2011)

The commonly used membership functions are a combination of trapezoid functions and triangle functions (Figure 4.5) and a combination of general bell functions and Gauss functions (Figure 4.6). As fuzzy systems are highly tolerant of the approximation of function shape, the identification of the membership function is not emphasized in the study. To simplify the computation, the Trap-Tri-Trap and

Gbell-Gauss-Gbell functions are adopted as the membership functions in this research. The function shape and corresponding equations are presented below.

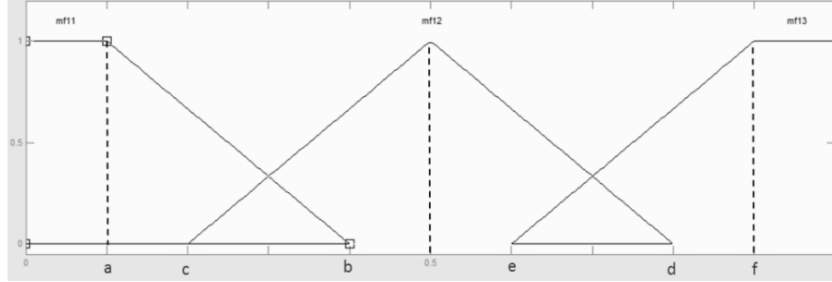


Figure 4.5 Trap-Tri-Trap Membership Function (Negnevitsky, 2011)

$$y = \begin{cases} 1; & 0 \leq x \leq a \\ \frac{b-x}{b-a}; & a \leq x \leq b \\ \frac{x-c}{0.5-c}; & c \leq x \leq 0.5 \\ \frac{d-x}{d-0.5}; & 0.5 \leq x \leq d \\ \frac{x-e}{f-e}; & e \leq x \leq f \\ 1; & f \leq x \leq 1 \end{cases} \quad (4.1)$$

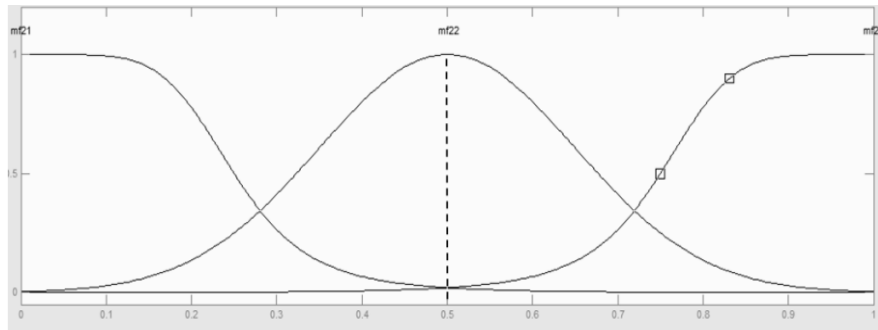


Figure 4.6 Gbell-Gauss-Gbell Membership Function (Negnevitsky, 2011)

$$\left\{ \begin{array}{l} f(x; a, b, 0) = \frac{1}{1 + \left| \frac{x-0}{a} \right|^{2b}}; \quad [a, b, 0] \\ f(x; \sigma, 0.5) = e^{\frac{-(x-0.5)^2}{2\sigma^2}}; \quad [\sigma, 0.5] \\ f(x; a, b, 1) = \frac{1}{1 + \left| \frac{x-1}{a} \right|^{2b}}; \quad [a, b, 1] \end{array} \right. \quad (4.2)$$

Fuzzy rules are generated based on expertise, designers' experience, lessons from practical cases, and indications from related research and publications to ensure that they are reliable to handle qualitative variables with concerns in fuzziness. The normal grammar of a fuzzy rule is:

**IF** *A is high, and B is high, and C is high*  
**THEN** *D is high*

**IF** states the conditions that comprise a series of facts, and **THEN** states the results. This rule can be interpreted as: when the “*degree of freedom DoIF*” is “*very free*”, the “*required human input in terms of operation*” is “*very complex*”, and the “*required human input in terms of attention*” is “*very serious*”, then the task that should be assigned in such conditions is “*high-class.*”

The operations between different facts are basically “*AND*” and “*OR*”. “*AND*” is the intersection, and “*OR*” is the union.

$$AND: A \cap B; \quad OR: A \cup B$$

However, there are some errors and biases in fuzzy rules owing to the nature of personal experience and knowledge. To rectify these errors and to improve the reliability of fuzzy rules, a back-propagation weighting training process is

developed to optimize the fuzzy system (Figure 4.7). Different weights are assigned to different rules. By loading the training sets and comparing the difference between ideal and actual outputs, the weights are continuously revised until the difference remains stable, and the weights can be regarded as optimal weights.

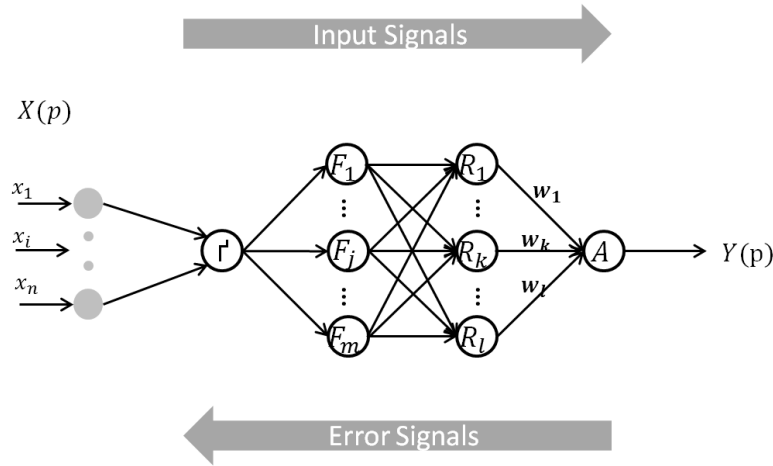


Figure 4.7 Weighting training process (Negnevitsky, 2011)

$$e_k(p) = y_{d,k}(p) - y_k(p); \quad (4.3)$$

where  $e_k(p)$  is the error between the ideal and actual output at the  $p$ th iteration,  $y_{d,k}(p)$  is the expected result of the  $k$ th neuron at the  $p$ th iteration,  $y_k(p)$  is the actual result of the  $k$ th neuron at the  $p$ th iteration

$$\delta_k(p) = \frac{\partial y_k(p)}{\partial X_k(p)} \times e_k(p) \quad (4.4)$$

where  $\delta_k(p)$  is the error rate of the  $k$ th neuron at the  $p$ th iteration,  $y_k(p)$  is the output function,  $y_k(p)$  is the actual result of the  $k$ th neuron at the  $p$ th iteration

$$\beta(p) = \text{sgn}(e_k(p)) = \begin{cases} -1, & e_k(p) < 0 \\ 0, & e_k(p) = 0 \\ 1, & e_k(p) > 0 \end{cases} \quad (4.5)$$

where  $\beta(p)$  is the direction of the weight correction

$$\Delta w_k(p) = \alpha \times \beta(p) \times y(p) \times \delta_k(p) \quad (4.6)$$

where  $\Delta w_k(p)$  is the weight correction,  $\alpha$  is the learning rate

$$w_k(p+1) = w_k(p) + \Delta w_k(p) \quad (4.7)$$

For training sets, they can be the limit case data. For example, the inputs are  $x_1 = [1, 1, 1]^{-1}$ ,  $x_2 = [0, 0, 0]^{-1}$ , and ideally the outputs are  $y_1 \in [0.9, 1]$ ,  $y_2 \in [0, 0.1]$ .

However, a neural network with a back-propagation algorithm is slow to converge, and it is easy to fall into a local minima in training. Considering this drawback, the method proposed by Dai and Liu (2012) is employed in this work to assist in achieving the optimal solution. Generally, all local minima points will be saved as possible solutions, and the most desirable solution will be selected competitively from all the possible solutions. Over-fitting is another common problem of neural networks with few hidden neurons. To tackle this problem, the penalty method is considered. A penalty term is derived and added to the error function to improve the generalization capability of this network.

Defuzzification is a process that combines the results of fuzzy rules and quantifies the result into a numerical format. As shown in Figure 4.8, the effect of every fuzzy rule is calculated according to the operation of the rule, and the union of all these effects is the effect area of the final result. To quantify the final effect, the commonly applied method is to calculate the centroid. The reference equations are listed below to explain the defuzzification process.

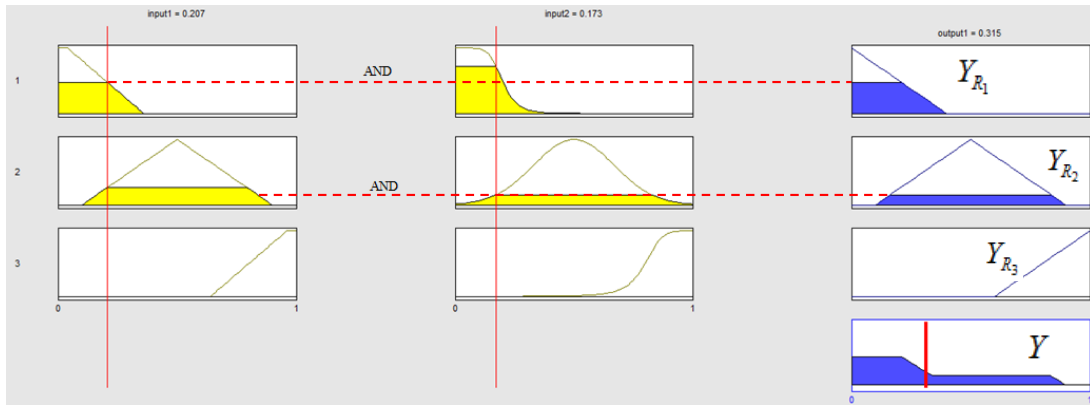


Figure 4.8 Rule evaluation and defuzzification (Negnevitsky, 2011)

$$Y = Y_{R_1} \cup Y_{R_2} \cup Y_{R_3} \dots \cup Y_{R_K} ; \quad (4.8)$$

where  $Y_{R_1}$  is the effect of rule 1,  $Y_{R_2}$  is the effect of rule 2,  $Y_{R_3}$  is the effect of rule 3,  $Y$  is the aggregation of effects of three rules

$$y = centroid(Y) = \frac{\int_a^b \mu(x) x dx}{\int_a^b \mu(x) dx} ; \quad (4.9)$$

where  $\mu$  is the membership function of output,  $a$  and  $b$  are respectively lower and upper limit of  $x$  value of  $Y$

In general, this neuro-fuzzy method is developed to use fuzzy methods to arrange the proper tasks that can best solicit the respondents' ideas according to the requirements of the product features.

### 4.3.3 Cheating control measures/principles

Cheating is one of the most important issues in crowdsourcing because of the anonymous nature of participation. To reduce cheating and to improve the effectiveness of the proposed model, a set of measures/principles are formulated to embed anti-cheating concerns in the initial stage of crowdsourcing development by enhancing the task design.

- ***Proper task order***

A reasonable arrangement of HITs can make the participants feel comfortable and keep them enthusiastic during participation. However, it is hard for participants to concentrate on every task. Thus, the order of the tasks should be determined carefully so as to effectively collect solutions to questions of different importance. For example, questions on the same topic should be grouped together. Questions on sensitive topics that might make respondents uncomfortable should be positioned at the end of the questionnaire (Krosnick and Presser, 2010). To force participants to slow down and pay more attention to important tasks, questions assigned can be more difficult or complex. For instance, blank-filling tasks require more attention for completion compared to single choice questions.

Moreover, similar questions could be arranged randomly to test whether the participants' answers are consistent. If not, it is an indication that the participants probably completed these tasks randomly, and the solutions may not be valid. For such questions, "gold units" (i.e., questions with absolute correct answers) are often adopted (Buchholz and Latorre, 2011).

- ***Verification questions***

Apart from setting an appropriate task order, verification questions are recommended to help reduce cheating further. Generally, verification questions are additional tasks that are included to test the respondents' performance. For example, assigners can assign basic background questions to test whether the

participants have really understood the requirements/instructions, and thereby judge whether they are able to give valid responses.

- ***Building rapport***

Another important factor that could result in cheating is the participation experience. If participants lose interest in completing a crowdsourcing project, they may be inclined to cheat or complete the task perfunctorily. For example, workload is one concern for building rapport. If the task load is too heavy, it will sap the participants' enthusiasm and force them to cheat to finish the project as soon as possible. Generally, a relaxing and harmonious user experience for participants should be ensured.

Through the establishment of the three modules, the proposed crowdsourcing system is expected to be able to i) decompose the innovation target, ii) identify the most suitable tasks, and iii) reduce cheating through improved task design.

#### **4.4 A case study on future PC design**

In this section, a crowdsourcing project is presented and illustrated. The project theme is an innovation case study on “*LifeBook: what PCs will be like in the near future*” by Fujitsu (LIFEBOOK is Fujitsu's laptop PC series associated with the concept of Life Partner: – “Always standing by your LIFE”).

Table 4.2 Main differences between typical and the proposed crowdsourcing

	<b>Typical crowdsourcing scheme</b>	<b>Proposed crowdsourcing scheme</b>
<b><i>Reward principle</i></b>	Winner reward	Grand reward to winners & Hourly wage to respondents with valid solutions
<b><i>Participants</i></b>	No special requirements on participants Solutions are verified and filtered after crowdsourcing	Verification questions are inserted during the design of HITs Only participants who meet the requirements of target participants will be involved
<b><i>Task allocation</i></b>	Lack of concerns on quantitative task allocation approach Tasks are usually arranged by developers intuitively	<i>A neuro-fuzzy network approach</i> is established to assist in identifying the most suitable tasks
<b><i>Cheating control</i></b>	Mathematical algorithms and statistical methods are applied to detect cheating after crowdsourcing	<i>A cheating control module</i> is developed which aims to reduce cheating by enhancing task design
<b><i>Innovation opportunity</i></b>	Few considerations are especially placed on supporting the creation of innovative ideas	A module of <i>innovation target analysis</i> is implemented to distinguish features free to be innovated and features constrained so as to facilitate the creation of effective innovative concepts

The proposed crowdsourcing system will be implemented with the same topic. Simultaneously, the crowdsourcing results of Fujitsu's project using a typical crowdsourcing scheme (data can be collected via the website of *designboom*) will be analyzed as a control group to be compared with the proposed system. The main differences between a typical crowdsourcing system and the proposed crowdsourcing system are presented in Table 4.2.

#### 4.4.1 Innovation target analysis

According to the information, the target is a future PC. First, the innovation target is analyzed with respect to the target participants, the main features to be designed, and the space for creativity. The target participants should be PC users. The main features covered by a PC design are shown in Figure 4.9. Every feature is denoted as “*Feature (degree of freedom, required human input in terms of operation, required human input in terms of attention).*”

According to the requirements of this project, the scenarios related to how a PC can be used are emphasized; therefore, usage scenarios can be freely created. The overall physical attributes are not the focus of this project. However, the product is required to be a mobile device, which means that the product should be highly portable. Hence, “*size,*” “*weight,*” and “*shape*” are partly free. “*Color*” is definitely free to be designed. For the hardware and interface, the basic configurations should be fixed, as they are technical issues and beyond the scope of this innovation. However, to match the special scenarios proposed by the participants, additional accessories and software applications are assigned with some freedom for innovation. The “basic functions” that a PC should be equipped with (e.g., accepting data, displaying data) are regarded as basic attributes, and “exciting functions” (i.e., functions beyond the expectations of users) are considered to support the creative design.

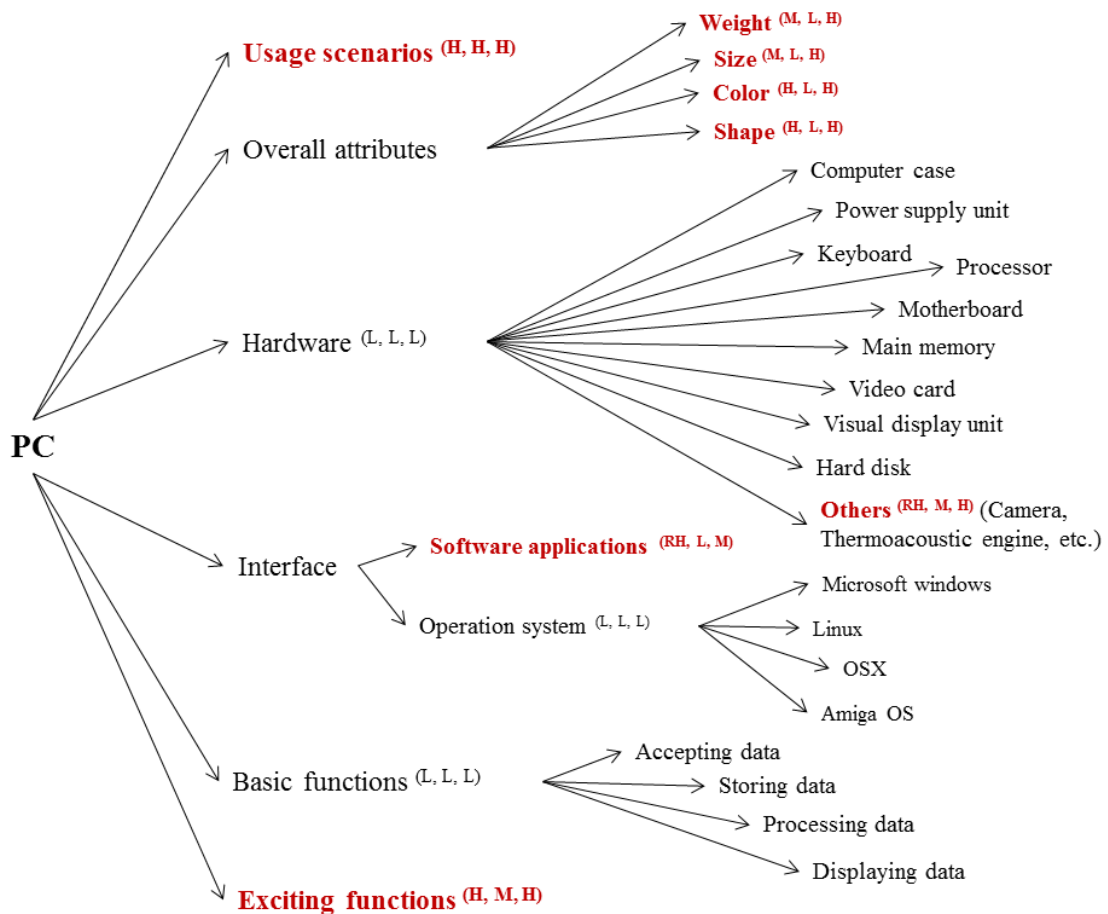


Figure 4.9 Innovation target analysis

(Requirement Level: VL=very low, L=low, RL=rather low, M=medium, RH=rather high, H=high, VH=very high)

Considering the estimation of the three dimensions, it is complex to quantify and measure product features, especially intangible features (e.g., color). Thus, fuzzy sets—which are highly tolerant of approximation—are employed. In this study, five levels (L = low, RL = rather low, M = medium, RH = rather high, and H = high) are set for innovation freedom, and three levels (L=low, M=medium, H=high) are assigned to human inputs in terms of operations and attention. Additionally, seven levels are assigned to output (VL = very low, L = low, RL = rather low, M = medium, RH = rather high, H = high, and VH = very high).

#### 4.4.2 Innovation-oriented HIT allocation

Table 4.3 Collection of membership functions

<b>Input variables</b>	<b>Membership functions</b>
<i>Innovation freedom</i>	L – Gbell [0.22, 3, 0] RL – Guass [0.065, 0.3] M – Guass [0.1, 0.5] RH – Guass [0.065, 0.7] H – Gbell [0.22, 3, 1]
<i>Human input in terms of operations</i>	L – Trap [0, 0, 0.4, 0.6] M – Tri [0.4, 0.6, 0.8] H – Trap [0.6, 0.8, 1, 1]
<i>Human input in terms of attention</i>	L – Trap [0, 0, 0.1, 0.4] M – Tri [0.2, 0.5, 0.8] H – Trap [0.6, 0.8, 1, 1]
<b>Output variable</b>	
<i>Task level</i>	VL – Trap [0, 0, 0.05, 0.3] L – Tri [0, 0.2, 0.4] RL – Tri [0.25, 0.35, 0.45] M – Tri [0.3, 0.5, 0.7] RH – Tri [0.55, 0.65, 0.75] H – Tri [0.6, 0.8, 1] VH – Trap [0.7, 0.95, 1, 1]

For the membership functions, the typical Trap-Tri-Trip membership function is adopted to describe the inputs (“*Human input in terms of operations*”, “*Human input in terms of attention*”) and the output (“*Task level*”) (Table 4.3). “*Innovation freedom*” is the focus of this project. Thus, it should be estimated carefully. To embody the complex influences caused by multiple factors (e.g., expertise and the definition of innovativeness) and to improve the approximation of the membership degree function of innovation freedom, nonlinear functions are preferred. As mentioned in Section 4.3.2.2, the general bell function and Gauss function are the

commonly adopted nonlinear membership functions and deployed for “*Innovation freedom*” in this study.

Subsequently, fuzzy rules are generated. Through continuous revisions and improvements, a rule base with a total of 34 fuzzy rules is built. The surface views of the rule base are presented in Figure 4.10.

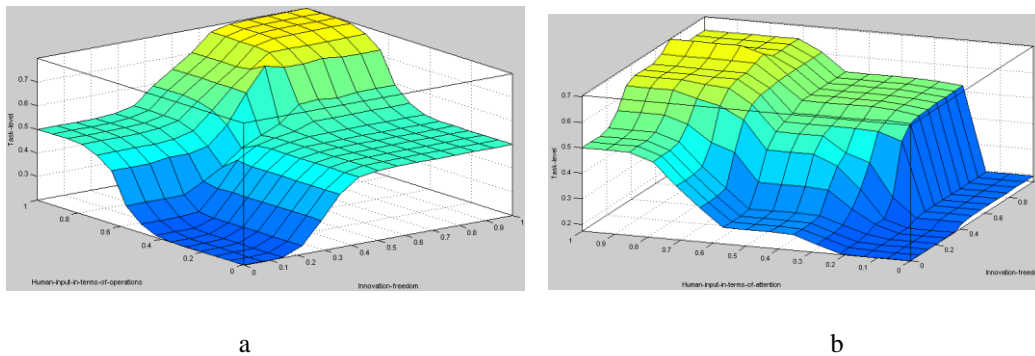


Figure 4.10 a Surface view of x-Innovation freedom, y- Human input in terms of operations, z- Task level; b Surface view of x-Innovation freedom, y- Human input in terms of attention, z- Task level

However, linguistic inputs should be transformed into a numeric format that can be processed by the fuzzy system. To give a more accurate estimation, a range was used to represent the linguistic variable, and the average value was computed as the crisp input. Therefore, the three dimensions of the inputs are obtained, as shown in Table 4.4. The output is obtained through the fuzzy system.

Table 4.4 List of inputs and outputs data

Design features		Fuzzy sets	Crisp input	Output
<i>Usage scenario</i>		(H, H, H)	(0.8~1, 0.6~0.8, 0.8~1)	(0.9, 0.7, 0.9) 0.8260
<i>Overall attributes</i>	<i>Weight</i>	(M, L, H)	(0.43~0.57, 0~0.4, 0.6~0.8)	(0.5, 0.2, 0.7) 0.4960
	<i>Size</i>	(M, L, H)	(0.43~0.57, 0~0.4, 0.6~0.8)	(0.5, 0.2, 0.7) 0.4960

	<i>Color</i>	(H, L, H)	(0.8~1, 0.4~0.6, 0.6~0.8)	(0.9, 0.5, 0.7)	0.6500
	<i>Shape</i>	(H, L, H)	(0.5~0.8, 0.4~0.6, 0.6~0.8)	(0.65, 0.5, 0.7)	0.6700
<b>Hardware</b>	<i>Regular parts</i>	(L, L, L)	(0~0.3, 0~0.4, 0~0.2)	(0.15, 0.2, 0.1)	0.1020
	<i>Others</i>	(RH, M, H)	(0.5~0.8, 0.4~0.6, 0.6~0.8)	(0.65, 0.5, 0.7)	0.6700
<b>Interface</b>	<i>Operation system</i>	(L, L, L)	(0~0.1, 0~0.4, 0~0.2)	(0.05, 0.2, 0.1)	0.0994
	<i>Software application</i>	(RH, L, M)	(0.5~0.8, 0.4~0.6, 0.6~0.8)	(0.65, 0.5, 0.7)	0.6700
<b>Functions</b>	<i>Basic</i>	(L, L, L)	(0~0.3, 0~0.4, 0~0.4)	(0.15, 0.2, 0.2)	0.111
	<i>Exciting</i>	(H, M, H)	(0.8~1, 0.6~0.8, 0.6~0.8)	(0.9, 0.7, 0.7)	0.801

#### 4.4.3 Cheating control measures/principles

During the task design, the measures/principles to control cheating are implemented. The HITs generated by the previous step are arranged according to importance. The important questions are positioned at the beginning, so that the participants have enough enthusiasm and concentration to carefully deal with these questions. For instance, the task of “Outlining the characteristics of your concept and specifying the features which are unique and special” is one of the most important tasks, and it is positioned in the first half of the crowdsourcing tasks. Further, the mood of the participants should be considered while sequencing these tasks. Sensitive questions that may make the respondents uncomfortable should be arranged at the end. For example, the question “What is the greatest motivation for you to participant in this project? 1) Interest; 2) Killing time; 3) Monetary reward”

is put in the final section. Similarly, some questions related to personal privacy are positioned at the end.

Secondly, some verification questions are randomly inserted to i) detect the background of the participants (e.g., whether they can provide valuable information) and ii) test the performance of the participants (e.g., whether they have understood the instructions). In particular, persons who have related knowledge and experiences about PCs and product design are the target participants for this project. Therefore, the questions are designed in the following manner: “Could you provide at least one computer technology which impressed you the most in recent years?” and “From your experience so far, please describe a time when you were involved in a design project or related activities.” In addition, verification questions are designed to test whether the participants’ answers are consistent. For instance, the questions “In the following two designs, which one is more user-friendly?” and “In the following two designs, which one is not user-friendly?” appear repetitively to test whether the participants are giving random answers.

Finally, the task load should be controlled at a proper level, and the user interface should be friendly. Overall, one day is sufficient to complete this project. There is no upper limit if the participants would like to generate CAD models or prototypes.

#### **4.4.4 Evaluation of innovative concepts**

Based on the HIT allocation results and the concerns related to cheating control, suitable tasks could be arranged, and all the crowdsourcing HITs could be built accordingly. The crowdsourcing HITs generated by the proposed system and the

crowdsourcing using the typical scheme are both posted on the web so that control testing can be conducted to validate the proposed crowdsourcing system.

#### 4.4.4.1 AHP process

To obtain innovative concepts from the crowd, an evaluation process of innovative concepts is executed, and the most innovative concepts are selected as the approved solutions that are to be rewarded. Some methods have been found to be useful and effective, such as the Pugh method, Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD) matrix method (Justel et al. 2007; Salonen and Perttula, 2005; Takai and Ishii, 2004). To organize the evaluation process hierarchically and emphasize the decision-making, the commonly used AHP method is adopted in this study. The general structure of AHP applied in the evaluation process is presented in Figure 4.11.

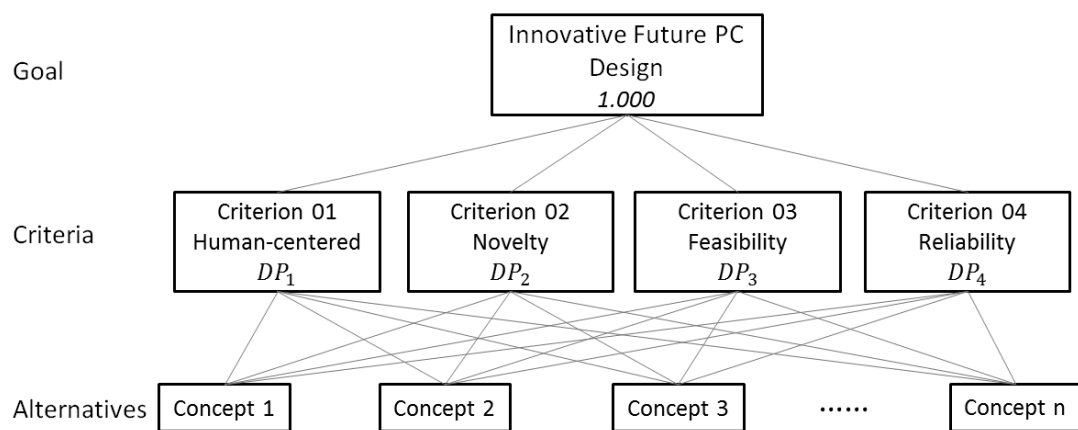


Figure 4.11 The structure of AHP concept evaluation method

Where  $DP$ : default priority;  $DP_1+DP_2+DP_3+DP_4=1.000$

#### 4.4.4.2 Strategy of concept evaluation

Based on the criteria that have been set by the project assigner (i.e., human-centered, novelty, feasibility, reliability), the performance of these concepts is assessed by a focus group that includes designers and Ph.D. students in the industrial and engineering design area. Based on their professional opinions, a relatively comprehensive comparison can be obtained.

Basically, the commonly used rating method Likert scale is adopted. However, personal bias is always disputed for most evaluation methods. To improve the reliability of the evaluation results, each criterion is broken down into more detailed items. Moreover, specific explanations for each criterion are given to provide more reference for the evaluators to make a reliable judgment (see Table 4.5).

Table 4.5 Decomposition of evaluation criteria (refer to Maguire, 2001; Dhillon, 1987)

<b>Human-centered</b>	Active involvement of users	This design encourages deeper user interaction
	Operating environment	Operating environment is friendly with consistency, clear navigation, error-free condition
	Ease-of-understanding	Users can easily understand the functions and the means to manipulate
	Ease-of-use	Required manipulation is simple and easy to learn
<b>Novelty</b>	New scenario	This design is motivated by a new application scenario
	Creative functions	This design proposes new functions and enable different operations
	Advanced technology	The technologies involved in this design are advanced or futuristic
	New operation mode	This design offers a new way to realize specified functions
<b>Feasibility</b>	Technology	The technologies required in this design can be realized in reality or not distant from being realized

	Manipulation	Required operations are properly designed and arranged
	Compatibility	The proposed design has high compatibility with existing PC, software, and accessories, etc.
	Manufacturing	The required materials are available; the foreseen cost and complexity of manufacturing is acceptable
<b>Reliability</b>	Use by novice	This design is safe, easy and comfortable for novice
	Redundancy	This design offers two or more means for carrying out the specified function
	Fault-tolerant	Specified functions could be executed successfully regardless of some error actions
	Maintenance	This design enables low-repair and easy maintenance

#### 4.4.5 Results and analysis

A comparison in terms of the quantity and quality of crowdsourced solutions is presented in Table 4.6.

Table 4.6 Results of the control testing

<b>Comparison</b>	<b>Typical crowdsourcing scheme</b>	<b>Proposed crowdsourcing system</b>
<i>Total number of collected solutions</i>	76	59
<i>Number of valid solutions (no cheating)</i>	69	56
<i>Percentage of valid solutions <math>P_v</math></i>	69/76=90.79%	< 56/59=94.92%
<i>Number of qualified solutions</i>	60	51
<i>Percentage of qualified solutions <math>P_q</math></i>	60/69=86.96%	< 51/56=91.07%
<i>Number of excellent innovative solutions</i>	6	7
<i>Opportunities to reach excellent innovations <math>P_i</math></i>	6/69=8.70%	< 7/56=12.5%

(Valid solutions = solutions with no cheating detected; Qualified solutions = solutions which meet innovation requirements; Excellent innovative solutions = solutions which are qualified and have the best innovativeness)

The results of this control testing show that the proposed prototype crowdsourcing system performs better than typical crowdsourcing. Firstly, the “percentage of valid solutions  $P_v$ ” is improved, which implies that the cheating control module may be helpful in reducing the cheating phenomena. Secondly, the proposed crowdsourcing system has greater chances of obtaining qualified solutions. Different from valid solutions, qualified solutions are defined as solutions that firstly do not involve cheating and subsequently meet the innovation requirements. In this case, the qualified solutions should be the valid solutions with certain creativity. By observing the parameter “Percentage of qualified solutions  $P_q$ ,” it can be found that the proposed crowdsourcing system is more effective in getting useful ideas. This improvement indicates that the innovation target analysis module may be useful in identifying target participants (i.e., those who are better able to provide useful knowledge) and in generating more valuable solutions. Thirdly, there are more opportunities to obtain excellent innovative ideas through the proposed crowdsourcing system. It can be seen  $P_i$  is improved by the proposed system, which implies that the HITs generated by the proposed method are more effective in collecting creative ideas from the participants. The analysis of the results indicates that the proposed crowdsourcing system is helpful in the creation of innovative concepts.

## **4.5 Chapter summary**

In summary, this research is intended to improve the crowdsourcing system in order to support the creation of innovative product concepts. Based on an analysis of prior research, three problems are identified: 1) a crowdsourcing system under a

systematic or unified framework for the purpose of supporting product innovation has not been well addressed; 2) it is imperative to establish an effective quantitative method to support the design of crowdsourcing tasks; and 3) few anti-cheating concerns have been embedded in the initial stage of task design. To tackle these problems, a crowdsourcing system is proposed. In particular, a crowdsourcing development approach is emphasized that consists of three modules: i) an innovation target analysis module, ii) an innovation-oriented HIT allocation module, and iii) a cheating control module. To realize these modules, a hierarchical architecture is structured to aid in the decomposition of the design target. A neuro-fuzzy approach is developed to identify suitable crowdsourcing tasks. In addition, a set of measures/principles is formulated to integrate anti-cheating concerns at the HIT design stage. The contrast test of an innovation project of future PC design indicates that the proposed crowdsourcing shows potential in the generation of more effective innovative concepts in terms of quantity and innovativeness of valid solutions.

Although the opportunities to achieve valid and innovative solutions are improved by the proposed system, there are some limitations. Firstly, the total number of participants is not as large as in a typical crowdsourcing setting. Since the proposed crowdsourcing system integrates more concerns about task design and cheating, the task load and difficulty are relatively heavier than in a conventional crowdsourcing setting; thus, the proposed crowdsourcing system does not seem all that attractive. However, the lack of attractiveness could be made up through other means, such as increasing the rewards. Secondly, the technique used in the proposed system can be further improved to enhance reliability and accuracy.

Therefore, it is envisaged that greater efforts need to be placed on explorations for increasing the attractiveness of the proposed crowdsourcing system and for improving the mathematical methods employed.

With this systematic and manageable crowdsourcing platform development approach in place, a sophisticated WKAP with sufficient focus on effective participation and effective responses could be established. Thus, a crowdsourcing environment (making the best use of crowd wisdom and simultaneously guaranteeing the basic quality of crowdsourced responses) is successfully created for facilitating concept generation.

# **Chapter 5 Sub-system 2 (AI-ICDP): A Product Concept Evaluation and Selection Approach**

## **5.1 Introduction**

As discussed in Chapter 3, AI-ICDP is intended to provide a platform for concept discovery from the crowdsourced concepts. To construct this platform, a product concept evaluation and selection (ProCES) approach is proposed. Corresponding to the research gaps identified in Chapter 2, a suitable data processing strategy specifically intended to cope with the complex crowdsourced conceptual design information deserves further exploration. Therefore, AI-ICDP focuses on providing an intelligent and efficient ProCES approach for processing the conceptual designs in a crowdsourcing environment.

However, in design practice, it is very challenging to deal with a large amount of crowdsourcing results efficiently. Traditionally, firms rely on their internal R&D to screen and evaluate design concepts; however, this method is not applicable in a crowdsourcing context because the workload might be extremely heavy. In addition, crowdsourcing responses might be in various formats (e.g., numerical value, textual description, graphics), which adds complexity to data processing. Moreover, the integration of design knowledge and principles into current data processing methods/algorithms for crowdsourcing has not been considered, which implies that a special emphasis on the characteristics of conceptual designs is still missing. Further, the evaluation results often rely on the designers' personal

knowledge and experience, which indicates that assistive quantitative decision-making is needed to enhance the reliability of the process of identifying better concepts.

Based on this understanding, ProCES built on data mining and domain ontology (further explanation about the reasons for selecting these techniques is given in the subsequent sections) is proposed to explore improved effective concept evaluation and selection in a crowdsourcing environment and to support the realization of AI-ICDP (Chang and Chen, 2014). Moreover, the following objectives are expected to be reached: 1) facilitate concept review and evaluation; 2) enhance crowdsourcing data processing methods/algorithms by embedding design knowledge and principles; and 3) support the decision-making process in order to identify better concepts in a simplified and systematic manner.

## 5.2 Overall architecture

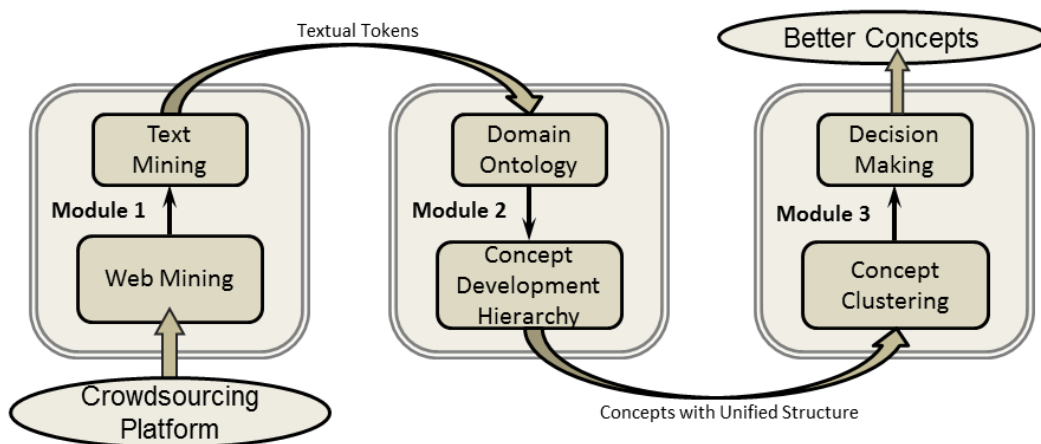


Figure 5.1 Overall structure of the proposed ProCES approach

Figure 5.1 presents an overall framework of the proposed ProCES in a crowdsourcing environment. Generally, the ProCES comprises three modules, and each of these modules realizes one of the three objectives identified in Section 5.1.

In **Module 1**, data mining is deployed to perform preliminary analysis on the large number of crowdsourced concepts. In particular, web mining is applied to crawl web logs and extract meaningful content from the initial online crowdsourced concepts. Subsequently, text mining is applied to discover textual patterns and to analyze the textual information in a quantitative manner. The main objective of this module is information extraction from the crowdsourcing platform.

In **Module 2**, the concepts are restructured using design knowledge and domain ontology. The connections between different word tokens extracted from the crowdsourced concepts are explored, and two kinds of connections are focused on, viz. design relation and semantic relation. The concept development hierarchy offers the base structure to reconstruct the crowdsourced concepts and leverages design knowledge and principles in building design relations. The domain ontology provides semantic and lexical references to bridge separate individual tokens and utilizes textual analysis to build semantic relations. The main objective of this module is to transform design concepts into a unified structure in order to facilitate the subsequent processing.

In **Module 3**, the concepts are clustered according to the unified concept structure; thus, concept selection can be simplified to a comparison of the clusters instead of comparing individual concepts. Through a multi-attribute and multi-criteria decision-making process, the cluster with better overall design quality can be

identified. Because of the integrated consideration of design and semantics issues, the identified better cluster has higher potential to contain excellent concepts. The objective of this module is to identify the promising concept candidates in a simplified manner.

In brief, the proposed ProCES is expected to reduce the burden of designers in reviewing crowdsourced concepts; leverage design knowledge in crowdsourcing data processing; and assist in identifying better concepts using a simplified and reliable decision-making process.

### **5.3 Information extraction from crowdsourced product concepts using data mining technique**

In the standard scheme of product conceptualization via crowdsourcing, a design project is posted online, and Internet users who are interested in this project can contribute their ideas. Normally, the number of crowdsourcing responses is huge. To deal with large crowdsourced concepts, data mining, which is a powerful data processing tool for managing large data, is adopted in this work.

#### **5.3.1 A brief review of data mining in product conceptualization**

For information extraction, data mining is an important tool to discover knowledge from a large amount of data. This tool has been widely applied in various industries.

Data mining is a generic term that covers various techniques such as clustering (Lv et al., 2011; Sousa and Wallace, 2006), association rule generation (Lee et al., 2012), and neural network (Cao et al., 2011; Chen and Liao, 2001; Mazhar et al.,

2007; Park and Seo, 2003). Clustering is mainly used for classification based on distances (similarities) between different concepts or designs. Association rule generation is used to find regularities between products in large-scale transaction data. It can deal with both numerical data and textual information. A neural network consists of an interconnected group of artificial neurons, and it processes information through a connectionist approach to computation.

In product conceptualization, data mining is helpful in dealing with a large number of qualitative design concepts (Yan et al., 2009a). For example, web mining provides an effective way of discovering textual patterns and extracting web content; text mining has advantages in analyzing textual information and deriving high-quality information from text context. Regarding the applications of data mining in product conceptualization, a framework was developed by He (2013) to improve user experience with case-based reasoning systems using text mining and Web 2.0. In addition, a text mining system built on an ontology to deal with diagnosis data in the automotive domain, was proposed by Rajpathak (2013). Text mining has been applied in opinion polarity classification, which helps decrease the sensitivity of ambiguous terms (Li and Tsai, 2013).

Crowdsourced conceptual designs are in a large amount, submitted through an online platform, and often represented using qualitative description. Therefore, data mining, which is a powerful data processing tool in such contexts, is emphatically considered. Specifically, web mining could be applied for extracting meaningful information from the online crowdsourcing platform, and text mining is suitable for dealing with qualitative conceptual designs.

### 5.3.2 Operations for extracting meaningful information from online crowdsourced concepts

In this study, a combination of web mining and text mining is proposed to extract useful information from online crowdsourced design concepts and to perform preliminary analysis on the extracted information. The pseudo code to briefly illustrate specific steps of the proposed method is presented here.

<p><u>Input:</u> An Excel file containing web links to be mined</p> <p><u>Output:</u> A collection of word tokens (*view of similarity results)</p>
<pre>START # WEB MING # 1. Create an Excel file of web links #The web links should be in fixed URL format# 2. Read each row as an example and each column as an attribute #The first row of the Excel sheet should be used for attribute names which can be indicated by a parameter; the data can be placed anywhere on the sheet and can contain arbitrary formatting instructions#   IF (empty rows OR empty columns) THEN     Set the cell value is missing     Assign only "?" to the cell   Else     Set the cell value is true;   End IF; 3. Crawl web pages via the true value i.e. web links in the cells #Set up simple crawling rules and store the crawled pages in a directory#   2a. Retrieve the entire webpage for each URL #HTML code will be added as an attribute#   2b. Save as an example set #The example set consists of two main attributes: the URL and the extracted HTML content#   2c. Verify if the HTML content value matches with the expected value type     IF (the content value does not match with the expected value type) THEN       Save the value as "?"     Else       Keep the value;     End IF; 4. Convert the example set to an object collection #Each row of the collection represents each example# # TEXT MING # 5. Process the object collection</pre>

```
5a. Tokenize #Linguistic tokens#
    IF (non-letter character) THEN
        Split
    Else
        Keep;
    End IF;
5b. Transform Cases
    IF (character in upper case) THEN
        Convert it to lower case
    Else
        Keep;
    End IF;
5c. Filter Stopwords #Set up filter rule, e.g. filter_stopwords_english,
    filter_stopwords_dictionary, filter_by_length#
*(optional) 6. Data to similarity #Calculate the similarity among examples; if there are n
examples, it returns (n)(n-1)/2 similarity comparisons#
    6a. Create vectors #Use TF-IDF to create word vectors#
    6b. Set similarity computation measures #mixed measure, nominal measures,
        numerical measures and Bregman divergences#
End;
```

## 5.4 Concept reconstruction using design knowledge and domain ontology

Concept reconstruction is intended to *organize the separate individual tokens extracted from design concepts into a unified structure*, so that the design concepts can be better understood from a design perspective and compared with each other. To realize this objective, a concept development hierarchy (CDH) is established based on design knowledge and concept development flow to provide the unified structure. By identifying the appropriate relations between tokens and CDH, these tokens will be properly reconstructed into a CDH-like structure. To build the connections, domain ontology, which is an important method for performing

textual analysis and identifying semantic relations, is adopted. Further, with the help of domain ontology, the interrelations among the tokens can be revealed.

#### 5.4.1 A brief review of domain ontology

Ontology is commonly used in information science to represent knowledge as a hierarchy using a shared vocabulary to denote the types, properties and interrelationships of concepts (Gruber, 1993). Domain ontology is a kind of ontology that is specific to domain interests.

**Definition 5.1** (Domain ontology). Domain ontology is specified by a set of concepts and a set of semantic relations, such as generalization, part of, relatedness, similarity, etc. In particular, the similarity relation is a ternary relation (Uschold and Gruninger, 1996):

$$\text{similarity}(c_i, c_j, \text{as}(c_i, c_j))$$

where  $c_i, c_j$  are concept names, and  $\text{as}(c_i, c_j)$  is the similarity degree in the interval  $[0.0, 1.0]$ .

Normally, semantic relations cover six specific types: similar (synonymous with), hypernym (is a kind of), hyponym (...is a kind of), holonym (is a part of), meronym (...is a part of) and attribute (...is a value of). These six types of semantic relations can be classified into two directions: one connects through superordinate association such as similar (synonymous with), hypernym (is a kind of) and holonym (is a part of), and the other one connects by identifying subordinate associations such as hyponym (...is a kind of), meronym (...is a part of), and attribute (...is a value of). For example, “length” is a kind of “physical

property”; thus, the connection between “length” and “physical property” could be built by finding the superordinate associated words of “length”. “Shortness” is a kind of “length”; thus, the connection between “length” and “shortness” could be built by finding the subordinate associated words of “length.”

To present the connections between tokens, an example of “water system” is given in Figure 5.2, in which three important semantic relations are considered. Often, the terms related in semantics are presented in a tree-like structure, as shown in Figure 5.3. In this hierarchy, the tokens at the higher levels are broader terms with relatively less information (Ross, 1976); while the tokens at lower levels are more specific and contain more information.

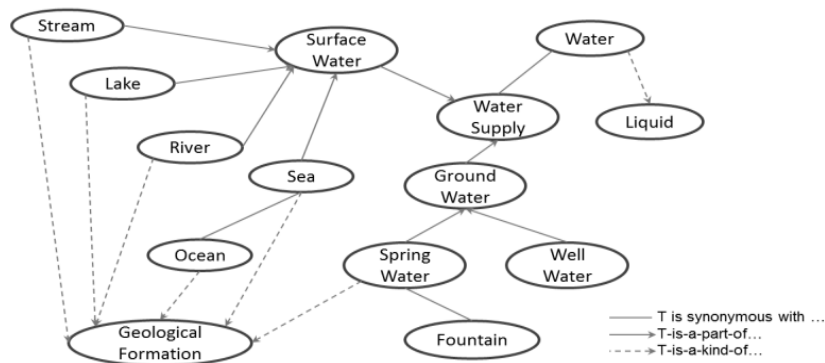


Figure 5.2 Tokens connected via proper semantic relations

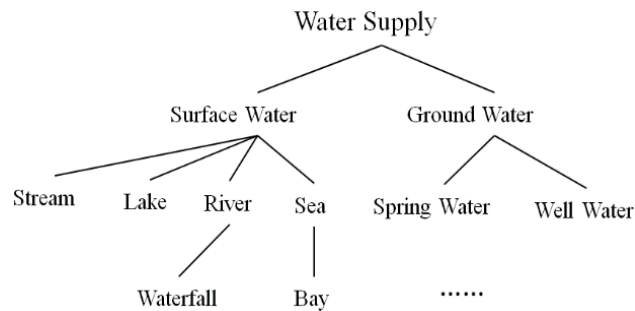


Figure 5.3 An example of semantic relation tree

Undoubtedly, domain ontology occupies an important position in knowledge engineering as a useful method for knowledge representation (Nomaguchi and Fujita, 2013). In PDD, ontology provides knowledge-intensive support for design information extraction and retrieval (Rahmani and Thomson, 2012). For example, domain ontology was applied with text mining to perform problem diagnosis in the product development process (Rajpathak, 2013). An ontology-based model of preference elicitation from customers was developed to facilitate concept generation (Cao et al., 2011). In addition, ontology was applied with case-based reasoning to evaluate design concepts (He, 2013). Thus, domain ontology might be helpful in the reconstruction of conceptual designs; therefore, it is employed in this study.

#### **5.4.2 Establishment of Concept Development Hierarchy (CDH)**

To construct textual tokens into a proper frame according to design knowledge and principles, CDH is developed to represent the designers' knowledge in a hierarchical structure (Figure 5.4). For a design concept, the primary concern is what this design can do for users. Therefore, a vivid description of the application scenario is expected, and the target functions should be specified. To realize the target functions, proper part design options (e.g., suitable functional mechanisms or settings) should be identified. Along with the explanation of the part design, the corresponding specifications (e.g., properties, attributes) of each component should be introduced. In this sense, CDH provides a systematic way to organize and present concept development knowledge through a unified structure.

In addition, most of the online crowdsourced concepts are expressed colloquially, which suggests that grammatical mistakes or illogicality may be unavoidable. Thus, it might be very difficult to understand and compare these concepts. Therefore, extracted tokens, which could keep all the information relatively complete and simultaneously remove the interference caused by poor semantic logic, might be more suitable for analysis and processing. Moreover, this justifies the need to organize concept tokens into a unified structure so as to improve the readability of concepts and facilitate the subsequent processing procedures.

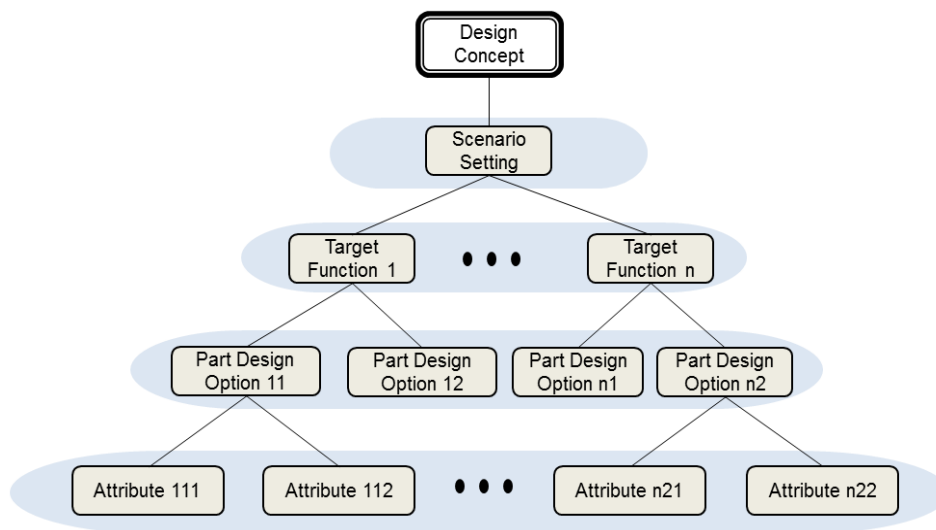


Figure 5.4 Concept development hierarchy (CDH)

### 5.4.3 Reconstruction of concept frame using extended ontology based on CDH

Based on domain ontology and CDH, the tokens extracted from crowdsourced design concepts can be related to one another from the semantics perspective and can be structured referring to the CDH from the design perspective. The detailed operations are as follows.

1. *Develop an extended design knowledge hierarchy*: As explained in Section 5.4.2, a layer-wise CDH is developed to embed the design knowledge in the concept reconstruction. Generally, the core frame to structure the tokens is the hierarchical architecture with the main concept development levels (i.e., scenario design, function design, part design, property design), which indicates that the tokens will be primarily sorted and put at corresponding levels with the best relevance. Considering the possible large amount of tokens extracted from each design concept, it could be quite challenging to ensure the proper reallocation of these tokens to the right level. To tackle this problem, an extended CDH is needed to provide more comprehensive reference for identifying the most suitable level on which to place the tokens. Therefore, important concerns or design elements at each concept development level are involved (Figure 5.5). For example, in the scenario setting stage, the target crowd, location, and activity are all important aspects for describing a design scenario. Thus, tokens describing or related to these aspects should be positioned at the scenario layer. Further, sub-concerns in each aspect (e.g., “height/width” to “overall size”) are also covered. On the other hand, to ensure ease of operation in textual analysis, linguistic labels are used to represent concept development levels and extended concerns or elements. An extended CDH with some sample linguistic labels is presented in Figure 5.5.

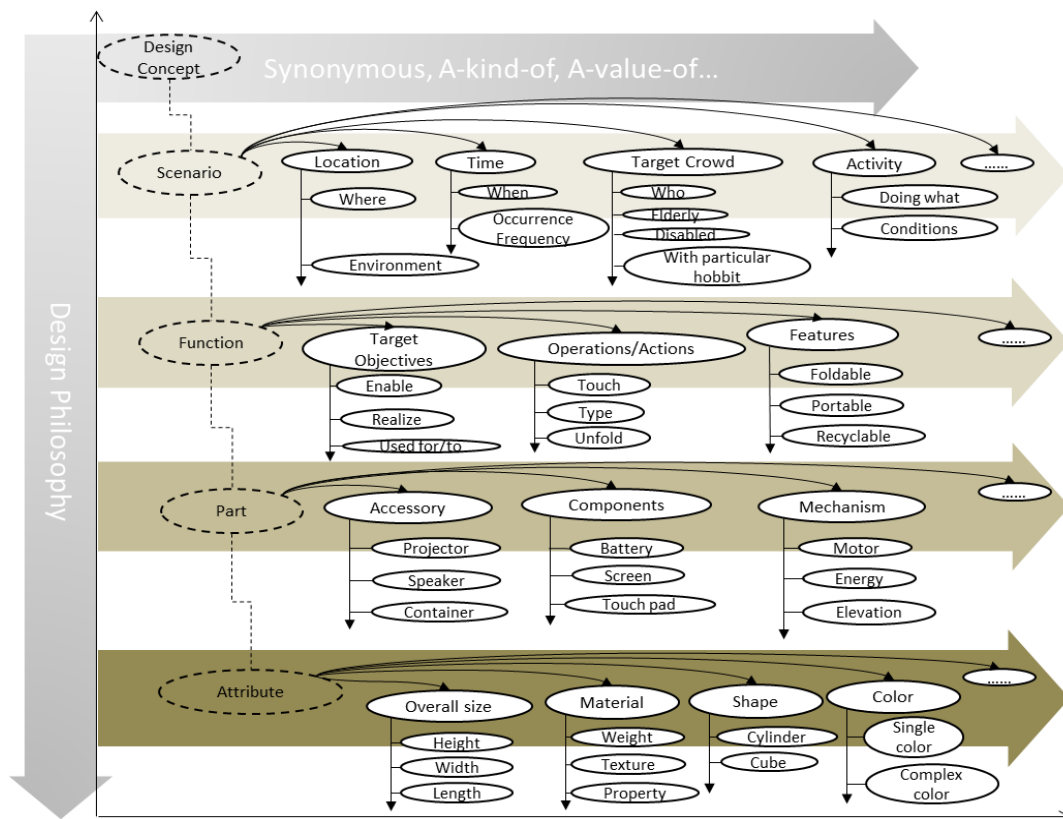


Figure 5.5 Extended design knowledge hierarchy

2. *Select proper semantic relations* to narrow the connections down to certain relations with relatively higher importance. As mentioned in Section 5.4.1, there are multiple types of semantic relations. However, not all of them are commonly used in document analysis. Referring to prior ontology-related studies, it appears that “synonymous” is the most frequently analyzed relation; often, it is treated as the significant parameter to measure semantic similarity. In this study, design structure is an important concern. Therefore, other relations that could be used for depicting the structural/component connections such as “meronym” (a part of) and “hypernym” (a kind of) are also taken into account. A proper set of semantic relations is needed for better textual analysis and to emphasize the relations with more importance.

3. *Build semantic connections*: This is a two-directional mapping and connecting process. To fully and systematically present the complex semantic relations, connections are developed mainly from two directions. As presented in Figure 5.5, in the vertical direction (i.e., y-direction), a hierarchical relation is deployed to constrain the tokens subject to concept development flow; in the horizontal direction (i.e., x-direction), synonyms, meronyms, and hypernyms are deployed to outline the interrelation between design elements and sub-concerns. Therefore, the specific operations for building semantic connections are generally divided into two steps: one is intended to layer the tokens according to the CDH levels, and the other is meant to relate tokens at the same level. At this stage, the lexical database is especially crucial for supporting the recognition of synsets and semantic relations. Amongst the existing lexical databases, *WordNet* is commonly used and is widely accepted as an important tool for identifying synsets. *WordNet* is an English lexical database developed by Princeton University (Formica, 2006). It contains English words with the definition of their lexical meaning, part-of-speech, synonyms, antonyms, familiarity, etc. With the help of lexical database, the connections between tokens can be realized.

3a. For the “y-direction layering,” the tokens of each design concept will be layered according to the CDH. The following steps are presented in Figure 5.6. *Step 1*: Individual tokens extracted from the design concepts in the example set and the linguistic labels derived from the CDH are mapped to the lexical database. In doing so, the corresponding words are expected to be found. For example, the textual token “*weight*” from a design concept and the linguistic label “*attribute*” from the CDH can be found with the corresponding words

“*weight (noun)*” and “*attribute (noun)*” in the lexical database. Since the lexical database contains most of the words in the Oxford dictionary, the words corresponding to the tokens and linguistic labels can be easily found. *Step 2:* The associated semantic relations between the mapped words have been defined in the lexical database, and these relations serve as an important reference for building the connections between the tokens and linguistic labels. For example, it has been defined that “*Weight is a kind of (Hypernyms) physical property or “attribute”*”. *Step 3:* The identified semantic relations are used to explore suitable connection types to bridge the tokens and linguistic labels. *Step 4:* The most suitable connections are utilized to define the relations between the tokens and linguistic labels, and the tokens will be placed at the level where the linguistic labels are successfully related to them. A descriptive presentation of this layering process is presented in Figure 5.7.

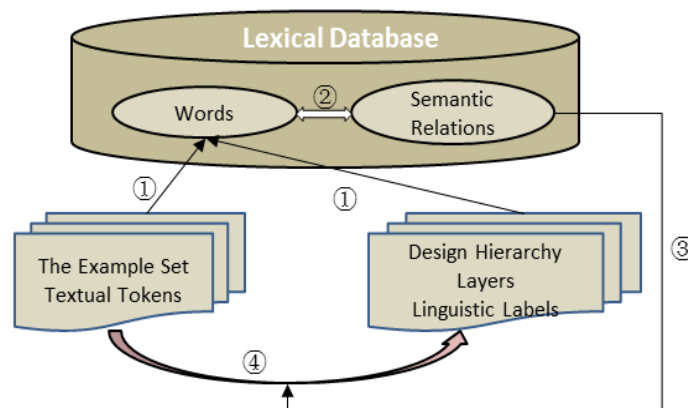


Figure 5.6 four-step mapping and connecting (y-direction)

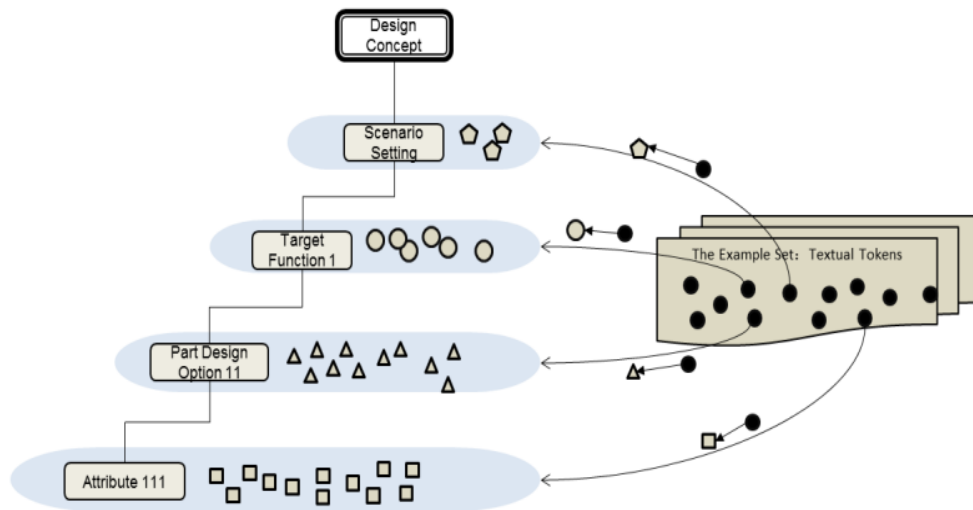


Figure 5.7 y-direction layering process

3b. For the “x-direction netting,” the tokens at the same level are connected to each other. Similar to the process for the y-direction, specific operations are divided into four steps as shown in Figure 5.8. *Step 1:* The tokens at the same CDH level are mapped to the lexical database to find the corresponding words. *Step 2:* The defined relations between the mapped words in the lexical database are identified. *Step 3:* The relations are used to identify the suitable connections to relate these tokens. *Step 4:* Once the most suitable relations are identified, these tokens can be connected to each other. Subsequently, a relation net to connect each token can be achieved. A descriptive presentation is given in Figure 5.9.

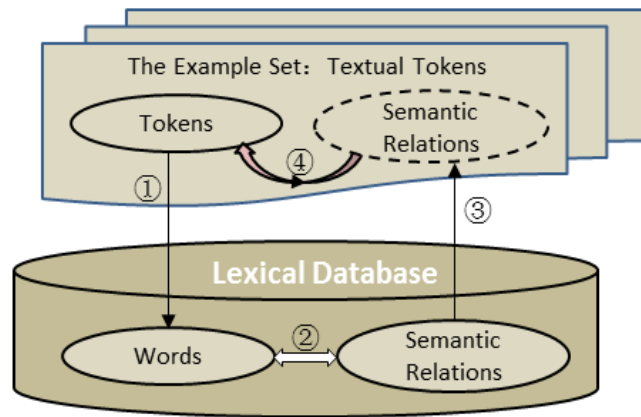


Figure 5.8 four-step mapping and connecting (*x-direction*)

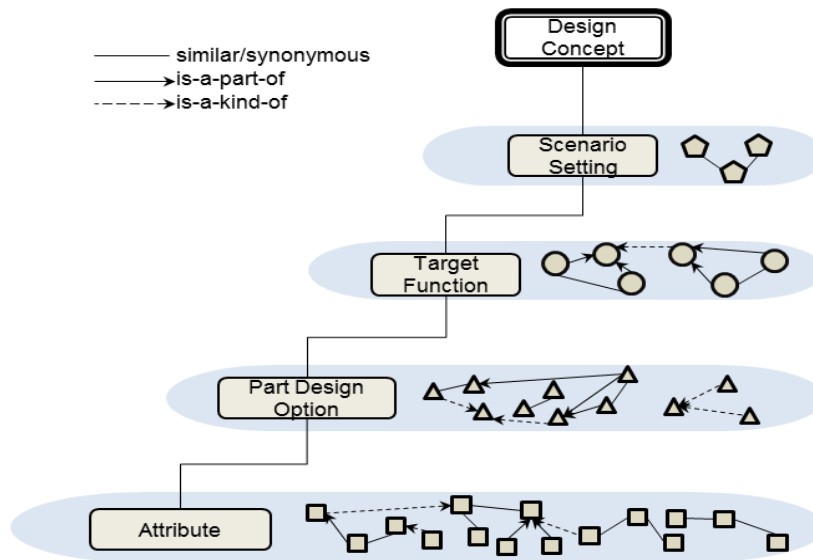


Figure 5.9 *x-direction* netting process

4. *Design concepts in a unified structure*: Through these steps, the individual tokens extracted from the design concepts are organized in a unified structure, as shown in Figure 5.10. By repeating the reconstruction operations, a consistent format could be obtained for the all design concepts, which could further simplify the analysis and comparison of different concepts.

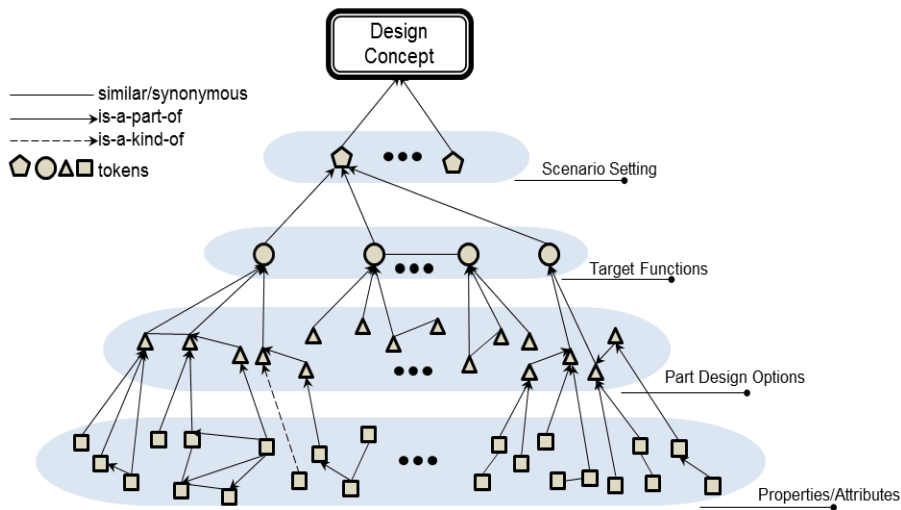


Figure 5.10 Design concept in a unified structure

## 5.5 Concept clustering and selection of promising concepts

Once the unified concept frames are in place, the comparison of these crowdsourced concepts is greatly facilitated. In this section, concept clustering is used to simplify the evaluation complexity; subsequently, a decision-making process is performed to identify better design concepts. In practical product conceptualization, there are often multiple design criteria and requirements to fulfill, which suggests that the evaluation and selection of concepts are actually a multi-attribute decision-making (MADM) process. Therefore, concept clustering and MADM are jointly considered in this module.

### 5.5.1 A brief review of related work on concept selection

In recent years, a large number of studies have focused on decision making in the context of product design (Inoue et al., 2012). For example, Yan et al. (2009b) developed an innovative product conceptualization strategy based on fuzzy integrals to facilitate product concept selection. As a discipline for handling

decision situations where a set of alternatives has to be assessed against multiple attributes or criteria, the MADM presents a logical alternative for tackling decision-making problems in product design. A design concept evaluation method of analyzing Pareto fronts in the MADM using level diagrams was developed to help the decision maker gain a better understanding of a conceptual solution (Reynoso-Meza et al., 2013). The MADM has also been used to test the usability of product design (Eraslan, 2009). Moreover, a study of the efficiency, effectiveness, and overall utility of representative MADM systems was conducted, which further demonstrated the importance of MADM in the conceptual design phrase (Lennon et al., 2013).

In addition, various techniques have been employed to support decision-making, such as analytic hierarchy process (AHP) (Eraslan, 2009), fuzzy set theory (Zhang and Zhu, 2008), fuzzy neural network (Hashiyama et al., 1993; Kong and Liu, 2006), etc. Among these techniques, the clustering technique has been applied widely and should be useful for especially dealing with crowdsourcing, where the number of responses is large. For example, a Kansei clustering approach was developed to identify consumer-consistent concepts through the clustering and evaluation of Kansei adjectives (Huang et al., 2012). To improve clustering accuracy, a text clustering algorithm based on frequent word meaning sequences was proposed (Li et al., 2008). For similar purposes, genetic algorithm and ontology have been integrated to enhance clustering effects (Song et al., 2009; Jing et al., 2006). Therefore, concept clustering is adopted to reduce the complexity of concept evaluation by summarizing similar concepts.

## 5.5.2 Concept clustering based on improved similarity

### measurement

For concept clustering, the principal concern is the estimation of the similarity between concepts. In this work, similarity is measured mainly in two respects: similarity in terms of semantics and similarity in terms of design knowledge.

Generally, one design concept can be treated as one document. The whole dataset can be represented as a collection of word tokens extracted from each document, as follows.

$$\phi : \left\{ w_{t_1, C_1}, w_{t_2, C_1} \cdots w_{t_{n_{C_1}}, C_1}, w_{t_{n_{C_1}+1}, C_1}, w_{t_{n_{C_1}+2}, C_1} \cdots w_{t_{n_{C_1}+n_{C_2}}, C_1}, \cdots \right\}$$

where  $w_{t_i, C_j} = tf - idf(t_i, C_j) = tf \times idf$  is the *TF-IDF* weight of textual token  $t_i$  in concept document  $C_j$ ;  $tf$  is the term frequency of indexing term in document;  $idf = \log(N/n)$ ,  $N$  is the number of documents in the datasets, and  $n$  is the number of documents in which the term appears.

Every design concept can be regarded as a set of word tokens. Normally, the submitted designs are described compactly and focus on explaining the main functions and features; relatively little attention is placed on detailed scenario setting. Hence, this study focuses on Target Functions, Part Design Options, and Property. All the textual tokens are divided into three subsets as shown below.

$$C = [w_{t_1}, w_{t_2}, w_{t_3} \cdots w_{t_m}] = \left[ (w_{t_1, tf}, w_{t_2, tf} \cdots w_{t_{m_{tf}}, tf}), (w_{t_1, do}, w_{t_2, do} \cdots w_{t_{m_{do}}, do}), (w_{t_1, pa}, w_{t_2, pa} \cdots w_{t_{m_{pa}}, pa}) \right]$$

in which:  $m_{tf} + m_{do} + m_{pa} = \tilde{m}$ ; where  $m_{tf}$ ,  $m_{do}$ ,  $m_{pa}$ , and  $\tilde{m}$  are integers;  $m_{tf}$  is the number of tokens at target function level;  $m_{do}$  is the number of tokens at design options level;  $m_{pa}$  is the number of tokens at properties/attributes level;  $\tilde{m}$  is the total token number in document C.

To calculate concept similarity, the three subsets should be compared, as they represent different design levels. Hence, the estimation of concept similarity can be regarded as a multi-dimension problem:

$$sim(C_1, C_2) = (sim_{tf}, sim_{do}, sim_{pa})$$

There are several measures available for measuring distance, such as Euclidean distance and cosine distance. Among these measures, cosine distance is commonly used in text/document clustering (Song et al., 2009; Wang et al., 2008; Yao et al., 2012; Nasir et al., 2013); hence, it is utilized in this study. For two concept documents  $C_1$  and  $C_2$ , the cosine similarity between them at the target function level can be calculated as shown in Equation (5.1). Similarly, the similarity at the other two levels (i.e., design options and properties/attributes) can be computed.

$$sim_{tf}(C_1, C_2) = \cos(C_1, C_2) = \frac{C_1 \cdot C_2}{\|C_1\| \|C_2\|} = \frac{\sum_{j=1}^{n_{C_2}} \sum_{i=1}^{n_{C_1}} w_{t_i, tf, C_1} * w_{t_j, tf, C_2} * (\bar{t}_i \cdot \bar{t}_j)}{\sqrt{\sum_{i=1}^{n_{C_1}} w_{t_i, tf, C_1}^2} \sqrt{\sum_{j=1}^{n_{C_2}} w_{t_j, tf, C_2}^2}} \quad (5.1)$$

where  $\bar{t}_i \cdot \bar{t}_j$  is the term correlation.

Term correlation can be obtained by estimating the semantic relations. For this purpose, a semantic relation tree is used, as it presents the related terms in a direct

and hierarchical structure (Figure 5.3). Two parameters in particular are important for measuring relatedness: path length  $l$  and depth  $h$ . Path length is the distance of the path from one term to the other. To illustrate using the example shown in Figure 5.3, the shortest path from *Waterfall* to *Bay* is “*Waterfall-River-Surface Water-Sea-Bay*”; thus, the minimal length of this path is 4. For depth  $h$ , it is the distance between the term node and the root node in the semantic relation tree. For example, the depth of *Surface Water* is “*Surface Water-Water Supply*” (i.e., 1), while the depth of *River* is “*River-Surface Water-Water Supply*” (i.e., 2). Thus, term correlation can be computed by integrating the considerations of path length and depth. Accordingly, the semantic correlation can be denoted as:

$$TermCorrelation = \bar{t}_i \cdot \bar{t}_j = f_1(l_{SRT}) \cdot f_2(h_{SRT}) \quad (5.2)$$

where  $l_{SRT}$  is the shortest path between terms in semantic relation tree;  $h_{SRT}$  is the depth to terms' common parent node in semantic relation tree.

With regard to  $f_1$ , it can be considered as an extension of Shepard's law (Shepard, 1987), which claims that exponential-decay functions are a universal law of stimulus generalization in psychological science. Moreover, it is a commonly used measure to resolve the issue of estimating relatedness through path tracking in a hierarchy (Song et al, 2009). Therefore,  $f_1$  is defined as:

$$f_1(l_{SRT}) = e^{-\alpha l_{SRT}}; \quad \alpha \in (0,1) \quad (5.3)$$

where  $\alpha$  is a real constant between 0 and 1; when the path length decreases to zero, the similarity would monotonically increase toward the limit 1, while the path length increases infinitely, the similarity would monotonically decrease to 0.

For  $f_2$ , since the terms at different depths contain different levels of informativeness (i.e., the upper layers contain more general information), the depth function (Song et al., 2009; Ehrig et al., 2005; Wang et al., 2008), which is useful to describe the observation, is used:

$$f_2(h_{SRT}) = \frac{e^{\beta h_{SRT}} - e^{-\beta h_{SRT}}}{e^{\beta h_{SRT}} + e^{-\beta h_{SRT}}}; \quad \beta > 0 \quad (5.4)$$

where  $\beta$  is a smoothing factor,  $\beta > 0$ .

As was discussed earlier, concept similarity is divided into three subsets ( $sim_{tf}, sim_{do}, sim_{pa}$ ), and these three subsets are subject to the CDH levels. Similar to the consideration of the depth in a semantic relation tree, the upper layers of the CDH represent a more general outline of a product, and the lower layers describe the product design more specifically. With reference to the depth function, the measurement of the overall concept similarity should take into account the influence of the CDH hierarchical depth. Thus, the overall concept similarity can be obtained by integrating the similarity at three layers, as shown in Equation (5.5).

$$sim(C_1, C_2) = sim_{tf} \cdot f_{2tf}(h_{CDH}) + sim_{do} \cdot f_{2do}(h_{CDH}) + sim_{pa} \cdot f_{2pa}(h_{CDH}) \quad (5.5)$$

where  $h_{CDH}$  is the depth to the root node in the concept development hierarchy (CDH).

In this work,  $k$ -means algorithm is adapted as a clustering method. In brief, the  $k$ -means algorithm is used to select  $k$  concept documents as initial centroids and subsequently assign other concepts to the nearest centroid based on the concept similarity measured using Equation (5.5). Once the initial clusters are identified,

the centroids of each cluster are recalculated, and the concepts are reassigned to their nearest centroids. This process is repeated until the optimal sum distance is achieved (MacQueen, 1967). The algorithm proceeds as follows:

1. Choose  $k$  initial cluster centers (centroid). For example, choose  $k$  observations at random.
2. Compute point-to-cluster-centroid distances of all observations to each centroid.
3. There are two ways to proceed:
  - Batch update — Assign each observation to the cluster with the closest centroid.
  - Online update — Individually assign observations to a different centroid if the reassignment decreases the sum of the within-cluster, sum-of-squares point-to-cluster-centroid distances.
4. Compute the average of the observations in each cluster to obtain  $k$  new centroid locations.
5. Repeat steps 2 through 4 until cluster assignments do not change, or the maximum number of iterations is reached.

### **5.5.3 Identification of promising concept candidates under multiple criteria**

Through concept clustering,  $k$  cluster centroids are critically analyzed as the representatives of the corresponding clusters. Firstly, a decision matrix  $D$  is assumed to represent the  $k$  concepts (i.e., cluster centroids). Each of these concepts is structured in three layers (i.e., target functions, design options, properties/attributes); thus, they can be treated as three-attribute data. Therefore,  $D$  is composed of  $k$  alternatives with three attributes.

Secondly, concept alternatives are evaluated according to certain design criteria. At this stage, designers need to be involved in order to provide their opinions, experiences, and knowledge for concept evaluation. A rating system is needed to quantify their evaluation. Every element of  $D$  (i.e.,  $x_{ij}$  represents one alternative with one specific attribute) will be scored under multiple criteria by multiple designers. In consequence, a scoring matrix  $s'_{ij}$  can be obtained for every element of  $D$ . The rows represent  $m$  design criteria, and the columns represent  $n$  designers.

$$D = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ \dots & \dots & \dots \\ x_{k1} & x_{k2} & x_{k3} \end{bmatrix} \rightarrow x_{ij} \rightarrow s'_{ij} = \begin{bmatrix} s'_{ij11} & s'_{ij12} & \dots & s'_{ij1n} \\ s'_{ij21} & s'_{ij22} & \dots & s'_{ij2n} \\ \dots & \dots & \dots & \dots \\ s'_{ijm1} & s'_{ijm2} & \dots & s'_{ijmn} \end{bmatrix}$$

However, different design projects may have different priorities for these criteria, and moreover, the influence of different designers on decision-making may be varied. To represent these concerns, the criteria weight matrix  $w_{cri}$  and designer influence matrix  $I_{des}$  are introduced and will be applied on the scoring matrix  $s'_{ij}$  in order to achieve a comprehensive evaluation score  $s_{ij}$  for the corresponding element  $x_{ij}$  of  $D$ , as shown in Equation (5.6).

$$w_{cri} = [w_1 \quad w_2 \quad \dots \quad w_m]; \quad I_{des} = [I_1 \quad I_2 \quad \dots \quad I_n]^T; \quad s_{ij} = w_{cri} \cdot s'_{ij} \cdot I_{des} \quad (5.6)$$

Once the evaluation score  $s_{ij}$  of each element  $x_{ij}$  of  $D$  is in place, a scoring matrix  $\bar{D}$  corresponding to the decision matrix  $D$  can be obtained.

$$\bar{D} = [s_{ij}]_{k \times 3} = \begin{bmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ \dots & \dots & \dots \\ s_{k1} & s_{k2} & s_{k3} \end{bmatrix}$$

Considering the practical design process, the design focus on these three attributes (i.e., function, option, attributes) may be different. Some design projects may focus on the exploration of new functions, whereas other projects may place more attention on environment-friendly features. To emphasize the varying design focuses on different design levels, a weight matrix  $w_{lay}$  is assumed and will be applied on the scoring matrix  $\bar{D}$  so as to achieve the overall evaluation score of every alternative. Finally, a matrix  $ES$  ( $k \times 1$ ), which contains the evaluation scores of all the alternatives, can be obtained using Equation (5.7).

$$w_{lay} = [w_{lay1} \quad w_{lay2} \quad w_{lay3}]^T$$

$$ES = \bar{D} \cdot w_{lay} \tag{5.7}$$

Based on  $ES$ , a ranking of all the design alternatives can be easily attained. With reference to this ranking, concept clusters with better scores can be identified. Because of the better overall design performance, the concepts in these clusters are identified as promising design concepts and selected as candidates for the good design concepts.

## 5.6 A pilot study on future PC design

A pilot study on future PC design is performed to demonstrate the proposed approach. A crowdsourcing product design platform “*designboom*” was selected as

the data source. This website provides access to a large number of design projects, and users can contribute their design solutions via the Internet. Among these projects, a future PC design project that was published by Fujitsu and received 108 concepts from worldwide designers was selected. Moreover, four requirements were specified for this project, which are: 1) *human-centered*, 2) *novelty*, 3) *feasibility*, and 4) *reliability*.

Normally, the submitted design concepts are presented in a combination of textual description and graphical interpretation; however, image processing is beyond the scope of this work. Therefore, the focus is on textual information, and concepts without any textual explanation will be removed. Moreover, the conventional concept review process will be performed in this case, and the results will be compared with the proposed ProCES. Considering 1) the anonymity of crowdsourcing and 2) the burden on the invited designers and experts to evaluate the concept candidates, a filtering process is needed, and the number of concepts should be controlled at a proper level. Hence, a preliminary study of 25 qualified concepts selected from crowdsourced concepts was conducted. The detailed operations of the proposed ProCES are divided into three stages corresponding to the three modules discussed earlier.

### **5.6.1 Information extraction stage**

A data mining process is deployed to extract meaningful textual information from the crowdsourced concepts. A powerful data mining software *RapidMiner* is applied. The deployment of the specific operators is shown in Figure 5.11. The main process consists of four operators (left side of Figure 5.11), namely, *Read*

*Excel*, *Get Pages*, *Data to Documents*, and *Process Documents* (corresponding to the operations defined in Section 5.3.2). Firstly, the related website links for a crowdsourcing project are collected, and their URLs are recorded in an Excel file. This is actually a pre-step to organize the target web links together for facilitating the information extraction procedures. *Read Excel* is employed to deal with the Excel file and to recognize the details in each cell. The *Get Pages* operator is functional in crawling the web sites, extracting HTML content, and verifying whether the content value matches the expected value type. Each design document is regarded as one example set. *Data to Documents* is utilized to convert the example sets to an object collection where each row represents each example document. Once the organized object collection is in place, the *Process Document* operator is responsible for specifically coping with the example sets. However, how to arrange the processing procedures depends on the analysis objective. In this study, a sub-process (right side of Figure 5.11) with three vector operators is designed. The operators are *Tokenize*, *Transform Case*, and *Filter Stopword*. *Tokenize* is used to split the HTML content and keep the characters between two neighboring splits as one token. *Transform Cases* is used to transform all the tokens into lower case so that the textual analysis is not case-sensitive. *Filter Stopword* is used to provide further rules to restrict the identification and representation of tokens. For example, *filter\_by\_length* is meant to filter tokens using a set value  $x$ , so that the tokens with more than  $x$  letters will be represented using the first  $x$  letters. Optionally, a *Stem* operator could be added so that the transformational words can be treated as one common stem during the processing. Through these operations, meaningful words (e.g., nouns, verbs, adjectives,

common phrases) are recognized and tagged as word tokens; other words/terms (e.g., preposition, postposition, blank space, punctuation) are subsequently removed. In consequence, each design concept is represented by a large number of individual tokens and phrases.

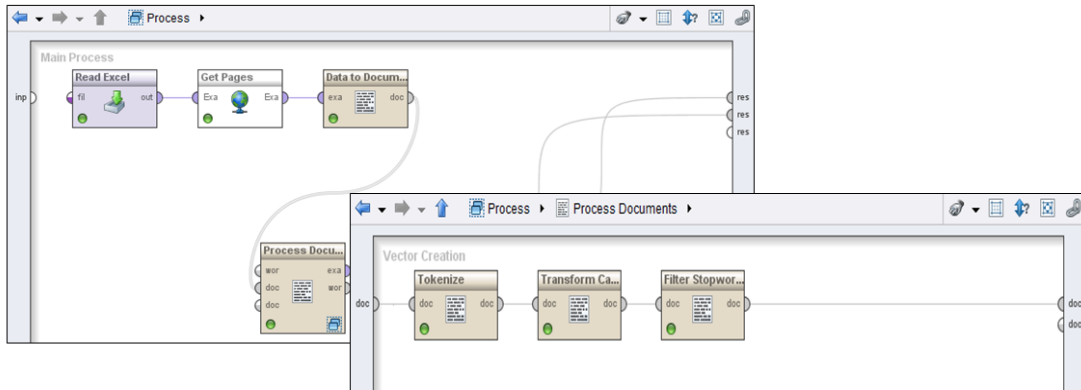


Figure 5.11 Screenshots of *RapidMiner*

For further explanation, the object file of the URLs is presented in Table 5.1, and some examples of the information extraction results are presented.

Table 5.1 URL collection and examples of extraction results

Con.	URL collection	Extracted token examples
1	<a href="http://www.designboom.com/project/crowd/">http://www.designboom.com/project/crowd/</a>	{ interface, touchpad, display, screen... }
2	<a href="http://www.designboom.com/project/integral-cord/">http://www.designboom.com/project/integral-cord/</a>	{ display, flexible, easily manipulate... }
3	<a href="http://www.designboom.com/project/anderson/">http://www.designboom.com/project/anderson/</a>	{ easy carry, two-way operating... }
4	<a href="http://www.designboom.com/project/the-haunted-mountain/">http://www.designboom.com/project/the-haunted-mountain/</a>	{ projector, light, stick, audio sensor... }
5	<a href="http://www.designboom.com/project/lifebook-frame-series/">http://www.designboom.com/project/lifebook-frame-series/</a>	{ detachable, multifunctional... }
6	<a href="http://www.designboom.com/project/ecopad/">http://www.designboom.com/project/ecopad/</a>	{ automatically, simply, day recharged... }
7	<a href="http://www.designboom.com/project/lifebook-hybrid/">http://www.designboom.com/project/lifebook-hybrid/</a>	{ drawing-pad, stylus, display... }
8	<a href="http://www.designboom.com/project/livepack/">http://www.designboom.com/project/livepack/</a>	{ heat electrical power, metal, screws... }
9	<a href="http://www.designboom.com/project/liquid-life/">http://www.designboom.com/project/liquid-life/</a>	{ touch screen, tablet, keyboard... }
10	<a href="http://www.designboom.com/project/im/">http://www.designboom.com/project/im/</a>	{ memory, mouse, flash memory card... }
11	<a href="http://www.designboom.com/project/fujitsu-gamer-lifebook/">http://www.designboom.com/project/fujitsu-gamer-lifebook/</a>	{ projector, wall-mounted screens... }
12	<a href="http://www.designboom.com/project/flexbook/">http://www.designboom.com/project/flexbook/</a>	{ touch screen, screen, seamless... }
13	<a href="http://www.designboom.com/project/lifebook-aio/">http://www.designboom.com/project/lifebook-aio/</a>	{ electronic paper scroll, software... }
14	<a href="http://www.designboom.com/project/fujitsu-life-bag/">http://www.designboom.com/project/fujitsu-life-bag/</a>	{ touch screen, fabric wooden edges... }
15	<a href="http://www.designboom.com/project/tray/">http://www.designboom.com/project/tray/</a>	{ slot base, wood, material... }
16	<a href="http://www.designboom.com/project/customize-like-your-imagination/">http://www.designboom.com/project/customize-like-your-imagination/</a>	{ carry, use times, customize... }
17	<a href="http://www.designboom.com/project/split-3/">http://www.designboom.com/project/split-3/</a>	{ user environment, organized, unify... }
18	<a href="http://www.designboom.com/project/nesting-pc-virtual-tablet/">http://www.designboom.com/project/nesting-pc-virtual-tablet/</a>	{ loading optical disk media, visualize... }
19	<a href="http://www.designboom.com/project/plus-3/">http://www.designboom.com/project/plus-3/</a>	{ easy, add, mini, choose... }
20	<a href="http://www.designboom.com/project/plantbook/">http://www.designboom.com/project/plantbook/</a>	{ hydrogen energy, leaf-shaped... }
21	<a href="http://www.designboom.com/project/fit/">http://www.designboom.com/project/fit/</a>	{ surfing, telephonic communication... }
22	<a href="http://www.designboom.com/project/lifebookleaf/">http://www.designboom.com/project/lifebookleaf/</a>	{ flexible, solar cells, displays... }
23	<a href="http://www.designboom.com/project/ceiyana/">http://www.designboom.com/project/ceiyana/</a>	{ compact, clear, surface... }
24	<a href="http://www.designboom.com/project/e-chat/">http://www.designboom.com/project/e-chat/</a>	{ create, eager communicate... }
25	<a href="http://www.designboom.com/project/all-screem-book/">http://www.designboom.com/project/all-screem-book/</a>	{ transform, electronic, downloading... }

### **5.6.2 Concept reconstruction stage**

The tokens extracted from each design concept are restructured with reference to the operations presented in Section 5.4.3. In this case study, the target product is the PC. Accordingly, highly important concerns related to PC design are developed and added to the base frame of the CDH. Since Target Functions, Part Design Options, and Property and Attributes are emphasized, an extended CDH is developed mainly around these three levels.

As shown in Figure 5.12, the function design could be extended into multiple directions, such as operation modes (OM), technologies applied, and user interaction (UI) methods. These issues indicate the ways to realize the target functions. At the part design level, some design options should be provided to further support the considerations in the OM, technology, or UI issues. In particular, what kind of functional mechanisms (FM) should be used is a crucial point in part design. Further, the components of FM (e.g., hardware, software, accessories) are expected to be designed and briefly presented. The associated properties or attributes of the components should be provided. For example, shape, color, size are important parameters to describe the components. Following the PC product development process, important concerns and necessary elements are added to the base CDH frame. Referring to this frame, more detailed options are generated and expressed using linguistic labels. For example, specific colors such as “red” and “azure” could be added to “color.” By extending each design concern into specific options, the linguistic labels are gradually filled in the extended CDH.

With the help of *WordNet*, 1) connections (i.e., semantic relations) between the tokens of design concepts and the linguistic labels of the CDH can be identified in order to layer the tokens at the corresponding CDH level, and 2) the connections between the tokens at the same level could also be identified. Once the semantic relations are identified, similarity measurement could be conducted.

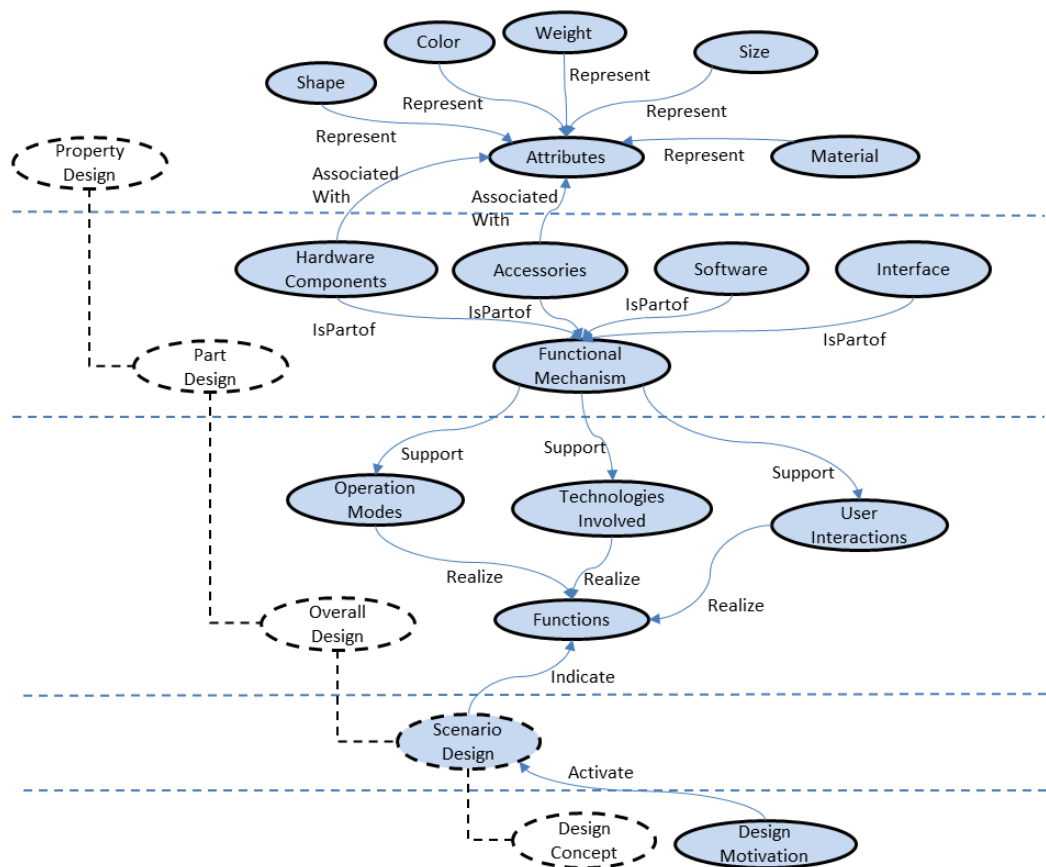


Figure 5.12 Extended CDH of PC product

### 5.6.3 Concept clustering and selection stage

The concepts are clustered using the *k*-means algorithm with improved similarity measurement, which integrates the consideration of semantic correlations (refer to Equations 5.1, 5.2, 5.3, 5.4) and the impact of different design levels (refer to Equation 5.5).

### 5.6.3.1 Expertise incorporation strategy

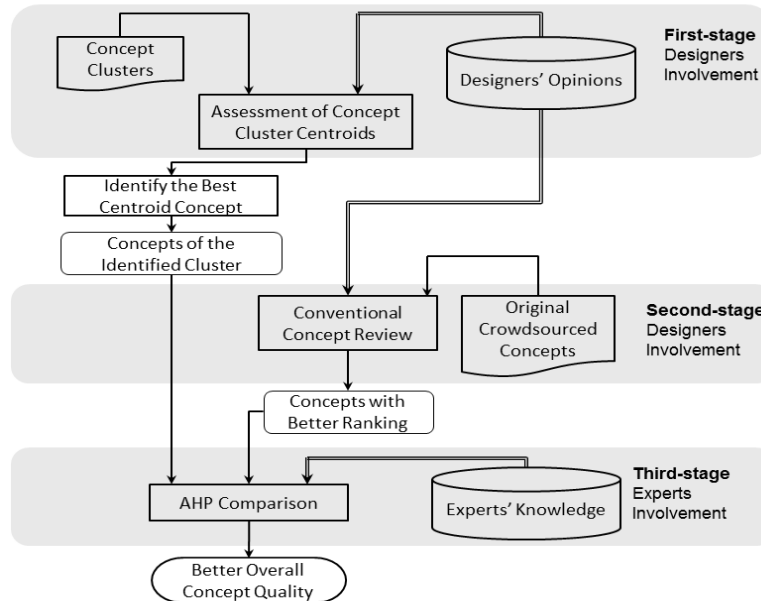


Figure 5.13 Designers and experts involvement

The designers' assessments are crucial inputs for the decision matrix. Therefore, the management of expertise incorporation is an important issue to be considered. Generally, a group of designers are engaged to provide their assessment about the cluster centroids in order to identify the best centroid. To compare the effect of the proposed ProCES and the conventional concept review method, the same group of designers is invited to provide their assessment about all the concept candidates so as to identify the better designs. The better concepts selected by the ProCES and the conventional way will be compared, and more experienced domain experts will be needed to make a relatively professional judgment.

Regarding the methods for designers/experts to give their evaluation, Pugh graph, QFD and Likert scale rating system are all commonly used, powerful methods. In this study, a 5-point Likert scale is applied. The operations are divided into three stages (see Figure 5.13).

*Stage-1 involvement:* Designers are asked to give assessments about the cluster centroids. The objective is to convert the designers' qualitative opinions into quantitative data that could be used in the decision-making process. In this study, the role of designers is taken over by eight Ph.D. students who all have more than 4 years' design study and rich product design experience.

*Stage-2 involvement:* Designers are involved in a conventional concept review process. The objective is to assess the original crowdsourced concepts and to select better concepts accordingly.

*\*A contrast between the proposed ProCES and conventional way will be made by comparing the overall design quality of the better concepts selected by these two methods. For the proposed ProCES, the concepts in the best cluster are considered as the promising candidates. For the conventional way, the concepts with higher assessment results are considered as the promising candidates.*

*Stage-3 involvement:* Experts are invited to evaluate the better concepts selected by these two methods. With the inputs from experts and the help of AHP, the overall design quality can be roughly estimated to provide a reference for the comparison. In this study, the role of experts was performed by four designers from Fujitsu who have over 10 years' design experience in business practice.

### **5.6.3.2 K-means clustering process**

Primarily, a process of identifying the proper  $k$  value is conducted. To examine the possible influence of  $k$ , a series of values are tested on  $k$  from 2 to 10. With fixed 10 replicates, concept clustering using Equations 1, 2, 3, 4, and 5 is performed.

The optimal sum distance is recorded as an important parameter to indicate the clustering accuracy. As shown in Figure 5.14b, the more divided the clusters are, the smaller is the sum distance.

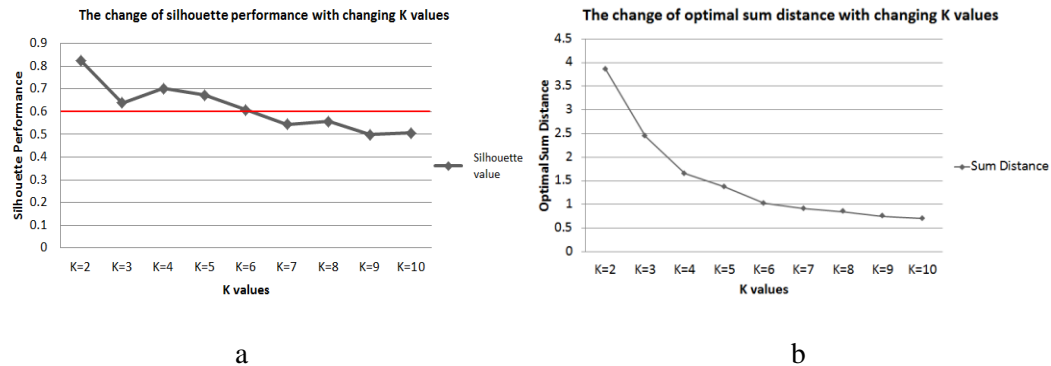


Figure 5.14 Study of changing  $k$  values (a. silhouette performance; b. optimal sum distance)

However, more clusters are not always better. The aim of concept clustering is to simplify concept evaluation by classifying similar concepts together. To ensure a proper sum distance and to simultaneously guarantee the validness of clustering results, silhouette value is introduced. The cluster number that leads to a clustering with silhouette value greater than 0.6 could be regarded as valid clustering. Referring to Figure 5.14a, it can be inferred that smaller cluster numbers have better clustering effect. By integrating the concerns of silhouette performance and optimal sum distance,  $k$  is finally set at 6. Moreover, the improvement trend of optimal sum distance begins to flatten after  $k = 6$ , which indicates that larger cluster numbers will not lead to significant improvement in clustering accuracy. The review scale is narrowed down from 25 to 6, which is an important improvement in review complexity. For  $k = 6$ , the clustering results are presented in Figure 5.15, and the centroids of concepts 2, 8, 9, 14, 16, and 25 are identified.

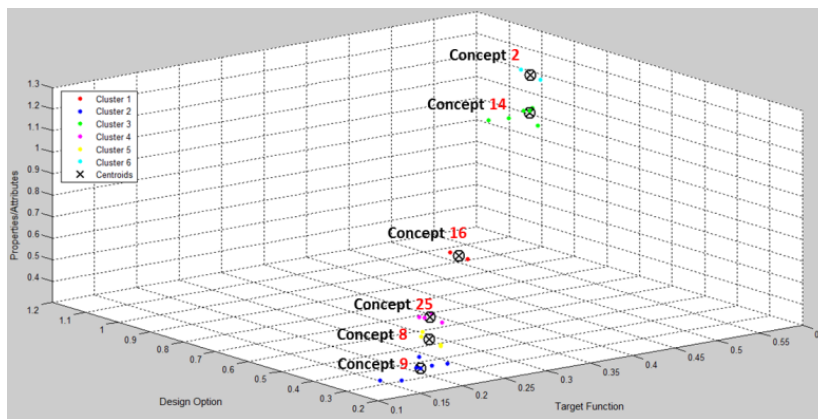


Figure 5.15 Clustering results with  $k=6$

Subsequently, these centroids will be assessed according to the design criteria. To do so, a group of eight Ph.D. students in the industrial and engineering design area was involved in the evaluation process. The weights of each criterion, the influence of different designers, and the priorities of different design levels are assumed to be the same.

Table 5.2 Assessment results on cluster centroids

Concept	$CV$	$w/I$	$ES$	$R$
2	0.848279	$w_{cri} =$		2
8	0.297707	$[0.25 \ 0.25 \ 0.25 \ 0.25]$	$\begin{bmatrix} 2.25 \\ 4.375 \\ 2 \\ 4.25 \\ 3.75 \\ 4.375 \end{bmatrix}$	5
9	0.267261	$I_{des} =$		1
14	0.350129	$[1/8 \cdots 1/8]_{1 \times 8}$		4
16	0.370328	$w_{lay} =$		3
25	0.422128	$[1/3 \ 1/3 \ 1/3]$		6

$CV$  is the coefficient of variance;  $w_{cri}$  is weight matrix of criteria;  $I_{des}$  is index matrix of designers' influence;  $w_{lay}$  is priority matrix of different design level;  $ES$  is evaluation score matrix;  $R$  is ranking

Through the calculation, a ranking of concept cluster centroids is obtained as shown in Table 5.2. Based on the ranking result, Concept 9 is identified as the best one. Moreover, *CV* of Concept 9 is relatively small, which indicates that the opinions of the designers about this concept are generally unanimously good. Since the other concepts in this cluster share relatively high similarity with Concept 9 from the design perspective, this cluster may have higher overall design quality and may have the largest possibility to contain the best concept; therefore, it deserves further analysis. The concepts in this cluster are: Concepts **1, 3, 4, 7, 9, 13, and 18**. These concepts will be studied as promising candidates for the best concept.

#### **5.6.4 Results analysis**

In this section, the better concepts selected by the proposed approach are compared with those selected through the conventional concept review method.

##### ***5.6.4.1 Concept evaluation through conventional concept review method***

The conventional concept review process relies heavily on the designers' time and labor to read and review the online concepts. Therefore, concept review in practical crowdsourcing design projects is usually burdensome. There is a lack of automated approach to help the review process; thus, designers often need to review the concepts manually. To control the influence caused by different reviewers, the same group of designers is involved in this process for evaluation. Similarly, a 5-point Likert scale rating system is used. The average score of their assessments is treated as the evaluation result, and the ranking result is shown in Table 5.3.

Table 5.3 Concept ranking results by the conventional approach

<b>Ranking</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>
Concept	6	1	11	5	18	9	3	20	23	25	19	2	16
<b>Ranking</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>	<b>21</b>	<b>22</b>	<b>23</b>	<b>24</b>	<b>25</b>	
Concept	7	12	22	15	17	21	13	14	8	4	10	24	

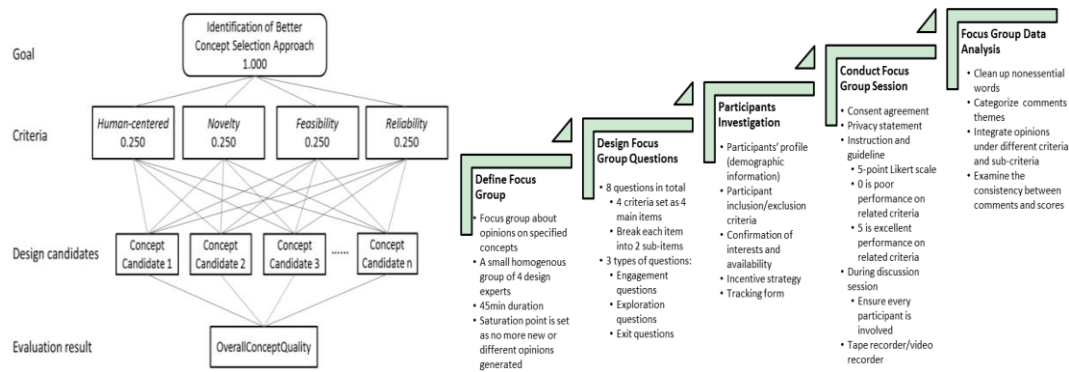
To compare the quality of the better concepts selected by the proposed method and by the conventional way, the best seven concepts selected by the conventional way are shaded (as shown in Table 5.3), because the better cluster identified by the proposed method contains seven concepts. In the following step, these two groups of concepts will be evaluated by domain experts; in particular, the overall design quality of the two groups will be estimated and compared, and the best concept among all these candidates will be identified.

#### **5.6.4.2 AHP comparison process**

AHP, which is a useful tool for organizing the evaluation process systematically and hierarchically, is deployed to identify the approach that can achieve better concepts. According to the criteria set by the project assigners, the performance of the best concept candidates will be assessed. A focus group of four design experts is formed to provide their professional opinions. Each concept candidate will be assessed, and the sum of the assessment results of the candidates in a group will be denoted as “*overall design quality (ODQ)*”.

Referring to Figure 5.16, in this project, four criteria were specified. To simplify the computation, it is assumed that all the criteria possess the same weight and priority; hence, the total weight 1 is equally shared by these criteria. During the

evaluation, a 0-5 scale system is adopted as the main scoring system to quantify the discussion results of the focus group.



a

b (Morgan, 1997; Krueger and Casey, 2000)

Figure 5.16 Expert evaluation process (a. AHP evaluation strategy; b. focus group arrangement strategy)

The assessment scores of each candidate will be loaded into the AHP process, and the estimated score of each concept candidate can be calculated using Equation (5.8):

$$ES_i = \sum_{j=1}^4 s_{ij} w_j \quad (5.8)$$

where  $s_{ij}$  is the score of  $i$ th concept candidate under  $j$ th design criteria;  $w_j$  is the weight of  $j$ th criteria

Table 5.4 Evaluation results on selected candidates

Concept	Design Criteria								<i>w</i> / <i>I</i>	<i>ES</i>
	Human-centered		Novelty		Feasibility		Reliability			
	$\bar{A}$	<i>CV</i>	$\bar{A}$	<i>CV</i>	$\bar{A}$	<i>CV</i>	$\bar{A}$	<i>CV</i>		
<b>1</b>	3.75	0.123	3.375	0.153	4.125	0.202	3.875	0.291		3.781
3	3.625	0.253	2.5	0.478	3.875	0.256	3.625	0.143	<i>w<sub>cri</sub></i> = [0.25 0.25 0.25 0.25]	3.406
4	3	0.356	3.875	0.256	2.625	0.404	2.625	0.283		3.031
5	3.5	0.265	3	0.309	4.25	0.166	3.5	0.153		3.563
6	3.25	0.218	2.625	0.349	3.375	0.417	3.5	0.404		3.188
<b>7</b>	4.25	0.109	3.75	0.276	4	0.231	3.875	0.165		3.969
9	3.25	0.273	3.875	0.091	3.5	0.265	3.5	0.305		3.531
11	2.625	0.197	3	0.356	3.625	0.205	3.125	0.113		3.094
<b>13</b>	3.625	0.253	3.125	0.317	4.125	0.202	3.875	0.256		3.688
18	3.625	0.143	4	0.189	3.375	0.271	3.25	0.273		3.563

$\bar{A}$  is average score, *CV* is the coefficient of variance; *w<sub>cri</sub>* is weight matrix of criteria; *ES* is evaluation score matrix

From Table 5.4, the *ODQ* of the better concepts selected by the proposed approach and the conventional approach can be estimated as:

$$ODQ_P = \sum_{i=1,3,4,7,9,13,18} ES_i = 24.969; \quad ODQ_C = \sum_{i=1,3,5,6,9,11,18} ES_i = 24.125$$

In addition, the three best concepts identified by the focus group (Concept **7, 1, 13**) are all candidates selected by the proposed method.

The evaluation results indicate that the overall quality of the better concepts selected by these two approaches is very close, and that the proposed method is slightly better. This may suggest that the proposed method is capable of identifying promising concepts with better design quality. Moreover, the best three concepts are selected by the proposed method, which further implies that the proposed method may have the potential to select good concepts more effectively. Further, the deployment of concept clustering greatly narrows the necessary review work

from 25 concepts down to 6 concepts, which indicates an important improvement in review efficiency. Generally, the proposed method not only reduces the review load but also ensures an effective capture of good concepts.

## **5.7 Chapter summary**

In this chapter, a product concept evaluation and selection (ProCES) approach based on data mining and domain ontology is established to assist designers in processing crowdsourced design concepts, and it is employed to realize the sub-system of AI-ICDP. In particular, three modules are developed, namely, a data mining module to extract meaningful information from crowdsourcing responses; a concept reconstruction module to organize the crowdsourced concepts into a unified form by integrating design knowledge and semantic concerns; and an assistive decision module to select the promising concepts in a more efficient manner. In other words, the application of intelligent techniques such as data mining could facilitate the concept evaluation and selection process, hence reducing the burden of designers in concept review. Further, the integration of design knowledge in structuring the design concepts enables a more reliable analysis of the crowdsourced concepts from a design perspective. Finally, a quantitative decision support process ensures a relatively reliable selection of promising concepts. A pilot study on future PC design was conducted to demonstrate this approach. It appears that the proposed approach is useful to: 1) extract information from the crowdsourcing platform effectively; 2) restructure the design concepts by fully integrating design knowledge; and 3) select promising concepts in an efficient manner.

However, some limitations remain. Although the proposed approach can facilitate concept evaluation and selection, the human labor of designers required in concept evaluation and selection in a crowdsourcing environment needs to be further reduced. Therefore, the specific methodology used in this approach has to be continuously improved. Moreover, in future work, a larger-scale case study needs to be conducted to further validate the proposed approach.

In summary, by developing the ProCES, the AI-ICDP could be constructed so as to provide a relatively intelligent innovation opportunity discovery platform. Once the promising concept candidates are identified, the blindness and hesitation in deciding which conceptual designs deserve further development could be moderated. Hence, a more concentrated detail design is anticipated.

# **Chapter 6 Sub-system 3 (CLRP): An Innovative Product Concept Retention Strategy**

## **6.1 Introduction**

As discussed in Chapter 3, CLRP is proposed to retain the concepts with leading advantage. On the one hand, it helps to further verify the identified promising concepts in terms of innovativeness. On the other hand, the retention of excellent concepts could benefit future PDD with similar requirements. To realize such a platform, the primary concern is to establish an innovativeness estimation approach. However, the definition of “innovativeness” is still misty, which leads to practical difficulties in measuring the innovativeness of conceptual designs.

The current market environment is increasingly competitive. Product innovativeness, which is a significant indicator of product success, has attracted much research attention and has been an important consideration to explore and identify the potential competence of products (Danneels and Kleinschmidt, 2001; Molina-Castillo et al., 2011). In fact, innovativeness is a broad notion, which could be labeled “variety,” “newness,” “relative difference,” and “changes.” (Augusto and Coelho, 2009; Garcia and Calatone, 2002; Danneels and Kleinschmidt, 2001) There are diverse definitions for innovativeness, and how to define innovativeness appears to heavily depend on the motivation for studying it. However, it is widely acknowledged that innovativeness should be a multi-dimensional (or multi-perspective, multi-attribute/determinant) construct. For example, Steinhoff (2010)

conceptualized product innovativeness in four dimensions, i.e., *degree of market information*, *degree of technological innovation*, *degree of organizational innovation*, and *degree of environmental innovation*. Szymanski et al. (2007) studied product innovativeness from a firm-based view and a consumer-based view. A simple analysis of the existing related studies reveals that product innovativeness is commonly conceptualized according to its influence levels, namely, innovativeness for consumers, innovativeness for firms, and innovativeness for the market. In general, researchers prefer to select the innovation-related factors/aspects that interest them as the dimensions for defining innovativeness. For example, Stock (2011) selected customer satisfaction as the main perspective to define and measure product innovativeness.

Regardless of the level, innovativeness is discussed beyond the scope of pure product design, and it involves concerns related to social and profitable effects. This indicates that innovativeness is often studied with the assumption that the product should be a mature product with complete product (lifecycle) information. However, it is the fuzzy front end that occupies a crucial position in new product design and development. As mentioned in Chapters 1 and 2, about 75-80% of a product's lifecycle cost is determined during the conceptual design phase (Duffy et al., 1993; Smith and Reinertsen, 1997). Thus, an exact perception of design quality in the conceptualization stage appears to be especially important (Akay et al., 2011; Chong et al., 2009). As one principal facet to reflect the potential competitive advantages of products, innovativeness deserves attention in the conceptual stage. Cho and Pucik (2005) asserted that the impact of product innovativeness on new

product performance relies on the quality of the new product design. Nevertheless, relatively little attention has been paid to the innovativeness of conceptual designs.

Further, most research related to product innovativeness involves empirical study (Danneels and Kleinschmidt, 2001; Bao et al., 2012; Steinhoff, 2010; Sethi et al., 2001), in which a Likert scale is often adopted as the main means for obtaining the rating scores from consumers or designers (Molina-Castillo and Munuera-Aleman, 2009; Danneels and Kleinschmidt, 2001; Augusto and Coelho, 2009). However, a rating method with fixed numerical levels as the scoring options, e.g., 5-point Likert scale: 1 (strongly disagree), 2, 3, 4, 5 (strongly agree), restricts the freedom of consumers or designers to give their assessment. They may choose the nearest option, which may not be exactly the desired one. Therefore, inaccuracy is unavoidably associated with the collection of evaluation data, which would further leads to a bias in the subsequent calculation of the appraisal result. To tackle these problems, an improved rating method that would allow for fuzzy or uncertain evaluation results is needed, as well as a scientific quantitative method that can deal with fuzzy inputs.

Based on the preceding analysis, it is perceived that innovative conceptual product design is a determinant of the success of the final product. Hence, how to measure the conceptual designs' innovativeness has become an important concern in new product development (NPD). However, relevant research to estimate the innovativeness of conceptual product design is scarce. Specifically, 1) *a clear and reliable definition of the innovativeness of conceptual product design is still missing*; in effect, 2) *effective innovativeness evaluation methods especially for*

*conceptual product design are scarce; and 3) a quantitative model dealing with the fuzziness and uncertainty involved in the evaluation results deserves to be examined.* Therefore, the motivation of this study is to tackle these problems.

## **6.2 Theoretical background of innovativeness of conceptual product design (ICPD)**

The multi-perspective and multi-dimensional construct for conceptualizing innovativeness is adopted in this study. To define the innovativeness of conceptual product design (ICPD), the peculiarity of conceptual design (i.e., product information at this stage is incomplete, fuzzy, and qualitative) should be fully considered. On the one hand, innovativeness is supposed to be estimated at a relatively macro perspective, since very detailed standards are hard to be judged according to the limited design information available. On the other hand, the product information is not so computable that the inputs of field experience and related knowledge from experts/designers are necessary. Because of the incorporation of expertise, personal bias is unavoidable and often hidden in the intuitive assessment (Cao, 2014; Desmet, 2012). Therefore, the emotional effect in innovation evaluation is worth studying to reveal the personal bias and, simultaneously, to reveal the tacit innovativeness associated with the intuitive assessment. Hence, a proper estimation algorithm could be developed in order to control the personal bias and fully consider the tacit innovativeness.

Based on these concerns, an affective perspective that is intended to specifically consider the emotional effect is proposed. Correspondingly, two perspectives are

studied, namely, cognitive perspective (offering normal innovation evaluation) and affective perspective (offering an attitude test).

### **6.2.1 Cognitive perspective: Hard innovativeness**

From the cognitive perspective, innovativeness is embodied by objective evidence. Therefore, multiple dimensions are generated to comprehensively conceptualize cognitive innovativeness. Considering the incomplete product information at this stage, these dimensions are generated at a relatively macro level.

#### ***6.2.1.1 New motivation***

The motivation for designing a product is the starting point of conceptual design and could be the primary embodiment of innovativeness. Therefore, new motivation is regarded as one dimension for characterizing cognitive innovativeness. In particular, a new application scenario and a problem to be creatively solved are the two factors driving new product designs.

- **New scenario:** It would inspire concept generation for creative products so as to fit the new application area and occupy a new market. For example, a scenario that involves a disabled person with the need to use a computer for learning or communicating in her/his daily life encourages the development of diverse creative concepts and tools, such as what Tang and Venables (2000) proposed. Similarly, various ambient intelligence techniques for facilitating the life of the aged are emerging recently (van Hoof et al. 2011). These examples indicate that a new scenario could provide the inspiration for developing new product designs.

- New problem: A problem that has not been solved well would motivate firms to seek creative solutions and to develop enhanced new products. Many firms keep improving their products and continuously launching new generations (e.g., the iPhone). The exploration for new solutions is a process for achieving innovativeness. Therefore, it appears that new problems could also lead to motivations for achieving new product design.

#### ***6.2.1.2 Latest advanced technologies***

Products can be classified into market-pull products (focusing on market demand) and technology-push products (focusing on new technologies) (Brem and Voigt, 2009), which strongly evidence the importance of new technology in NPD. The breakthroughs brought about by new technologies often determinately lead to the creativity of products. Thus, the involvement of new advanced technologies might be a characteristic of cognitive innovativeness.

- New technologies that have not been applied in established products: For example, Apple acquired FingerWorks and its multi-touch technology in 2005 and created a new vision for smartphones. The iPhone has been depicted as a leading innovative product. In addition, Amazon's Kindle is a successful example that uses e-paper and e-ink technologies to achieve innovative e-book readers. These product innovations show that the rapid development of new technologies has significant power to bring about innovativeness.
- Brand new technologies that need to be developed to fit boldly creative product design: In some cases, there are no existing technologies to realize

the design objectives. Thus, the key techniques may need to be invented by the firms themselves. This phenomenon can be found in technology industries such as software companies. They tend to develop their own patented products (e.g., IBM, Samsung, Canon). Undoubtedly, it also forms an important motivation for achieving innovativeness.

### ***6.2.1.3 New functionality***

Functionality is the main arena for product innovation. It is an important concern in outlining the general product concept and is regarded as a factor that possibly embodies cognitive innovativeness.

- Creative functions often require new operation modes or changes to the existing mode of operation. For example, a voice-activated switch enables the function to switch on/off electric appliances with the users' voice. This indicates a big change in the users' behaviors in using switches. Another example is Siri, which provides a completely new mode for operating smartphones. These creative functions lead to changes in the users' operations, and this kind of change often implies an innovation in product design.
- Creative user interaction is another factor leading to product innovation. The emerging virtual reality (VR) techniques and related products are good evidence of this. For example, Oculus Rift is an impressive design that could completely change the interaction manner of video games. Microsoft is planning a major project to realize VR in its Xbox by integrating Oculus Rift in order to immerse players in the game. Moreover, user interface (UI)

design is an important arena for innovativeness. For example, the changes in website navigation design would affect the users' operations. Therefore, a better UI design could result in successful innovative products.

From the cognitive perspective, the factors that have a significant influence on product innovation are summarized earlier.

## **6.2.2 Affective perspective: Soft innovativeness**

In the conceptual design stage, the limited product information and visual presentation often lead to a space for reasonable inference and prediction. According to Arnold (1960), "emotions are always responses to stimuli which are determined in an appraisal or sense evaluation of the extent to which the stimulus has an impact on one's well-being." Therefore, evaluation and estimation actually require the evaluators' accumulated experiences and professional knowledge in related areas, and this kind of evaluation is tacit and expressed in an intuitive way. For this reason, the study of the emotional effect related to the evaluation process is worthwhile. In particular, three facets are highlighted: attraction, uniqueness, and adoption.

### **6.2.2.1 Attraction/Desire**

"Attraction refers to a quality that causes an interest or desire in something or someone." (Andrew et al., 1990) In the product design area, it is defined as "a visceral-level phenomenon, a reaction to the object's appearance," and visual appeal is generally regarded as the main stimulus that causes the emotion of attraction (Lee, 2007; Lin et al., 2013). Desmet (2012) conducted an in-depth study and revealed that attraction—which is often accompanied by love and desire—is an

important positive emotion in human-product interactions. These prior studies reveal that attraction is actually a direct reaction to design quality. In particular, stronger attraction may indicate the evaluators' higher confidence with respect to a design.

Similarly, in innovativeness appraisal, attraction could reflect the degree of recognition of the evaluators regarding how innovative a product design is. Therefore, it is identified as one dimension for evaluating the emotional innovativeness of conceptual product design at the impression level.

#### ***6.2.2.2 Uniqueness/Pleasant surprise***

Uniqueness is a product characteristic that could “constitute a tension field by defining a design space that excludes existing design solutions.” (Desmet et al., 2007) However, according to the uniqueness theory, high levels of similarity and dissimilarity could both lead to unpleasantness, and people prefer a moderate level of distinctiveness to other levels (Snyder and Fromkin 1980; Goldsmith et al., 2007). This finding suggests that uniqueness cannot be simply explained by the degree of dissimilarity. Thus, it is necessary to distinguish whether or not the response to suddenness or unexpectedness is pleasant.

Innovativeness evaluation focuses on positive emotions, which represent more opportunities to reach better innovative designs. Therefore, “pleasant surprise” is proposed to describe the reaction to the desirable or pleasurable unusualness (Desmet, 2012), and it is used to define uniqueness in this study. Further, uniqueness or pleasant surprise is the most direct facet that represents the degree of

novelty and newness from the emotional perspective. Therefore, it is identified as an important dimension for measuring emotional innovativeness.

### ***6.2.2.3 Adoption/Acceptance***

Adoption is the feeling of acceptance and approval (Desmet, 2012). Especially for product innovation that aims to offer extensive changes, adoption risk is a research focus (Steinhoff, 2010). For example, Hauser et al. (2006) argue that the success of innovation depends on consumer adoption. Goldsmith and Foxall (2003) hold a similar view that many new products eventually fail because of low adoption rate. Moreover, the characteristics of new products such as complexity, compatibility, divisibility, and communicability are found to affect adoption rate (Rogers, 1995). Hence, it appears that adoption risk in product innovation is sensitive and should be carefully controlled. It also implies that innovativeness is not completely open to newness and changes. The analysis of innovativeness is practically meaningful only if the innovation is acceptable. Therefore, adoption/acceptance level is considered as a crucial dimension in innovativeness estimation.

In brief, ICPD is characterized by new motivations, technologies, and functionality from a cognitive perspective, and by attractiveness, uniqueness, and adoption from an emotional perspective. In the following sections, ICPD will be measured and estimated according to this definition.

## **6.3 A grey-based fuzzy concept innovativeness estimation approach (GF-CIEA)**

In this section, a quantitative method to estimate ICDP is proposed. In general, the designers' opinions and assessments about the facets that characterize ICPD will be collected as raw data. Subsequently, the assessment data is processed, and a mathematical model based on grey numbers and fuzzy logic is proposed to calculate ICPD.

### **6.3.1 An enhanced innovation evaluation process**

This is the primary stage to collect the evaluators' assessments about the design candidates. Prior studies related to concept evaluation or assessment indicate that rating or scoring is necessary. Since the rating process involves fuzziness and uncertainty, an enhanced innovation evaluation process that allows fuzzy and uncertain inputs is needed. Accordingly, three specific concerns of a rating-based evaluation process, i.e., assessment criteria, rating method, and weighting/prioritizing method, are emphasized.

#### ***6.3.1.1 Design of assessment criteria with reference to ICPD***

Referring to the definition of ICPD, there are two perspectives that deserve to be studied. From each perspective, the factors that may have an impact on innovativeness are identified in order to characterize ICPD. The assessment criteria are generated according to these factors. Table 6.1 summarizes the assessment criteria.

Table 6.1 Assessment criteria

<p><b>Cognitive perspective</b></p> <p><u>New design motivation</u></p> <ul style="list-style-type: none"> <li>• To what extent is the concept aimed at new customers to your firm that you had not sold before</li> <li>• To what extent does this concept cater to new customer needs – customer needs that you had not served before</li> </ul> <p><u>New technology</u></p> <ul style="list-style-type: none"> <li>• To what extent does the technology involved in this concept represent a new or different technology from your firm</li> <li>• To what extent are your firm’s R&amp;D product development resources, people, and skills more than adequate to handle the development of this design concept</li> </ul> <p><u>New functionality</u></p> <ul style="list-style-type: none"> <li>• To what extent does the functions proposed in this concept represent a new or different function from your firm</li> <li>• To what extent does the operation mode incorporated in this concept represent a new or different operation mode from your firm</li> <li>• To what extent does the user interaction way incorporated in this concept represent a new or different user interaction from your firm</li> </ul>
<p><b>Affective perspective</b></p> <p><u>Attractive</u></p> <ul style="list-style-type: none"> <li>• To what extent are you attracted by this design concept at your first impression</li> </ul> <p><u>Unique</u></p> <ul style="list-style-type: none"> <li>• To what extent are you pleasantly surprised by this design referring to your previous experience and knowledge</li> </ul> <p><u>Acceptable</u></p> <ul style="list-style-type: none"> <li>• To what extent can you accept this design concept as a product that you will develop and then sell to the market</li> </ul>

### 6.3.1.2 Design of improved rating method

Some commonly applied concept evaluation methods are summarized in Table 6.2. The procedure of rating/scoring appears to be necessary for concept evaluation and deserves deliberate consideration.

Table 6.2 Common concept evaluation methods

ABC analysis	<ul style="list-style-type: none"> <li>• Sorting and categorization</li> <li>'A' items are very important</li> <li>'B' items are important</li> <li>'C' items are marginally important</li> </ul>
Anonymous voting	<ul style="list-style-type: none"> <li>• Select a short list of ideas</li> <li>• Rank them according to their significance.</li> </ul>
Checklist	<ul style="list-style-type: none"> <li>• Design criteria questions</li> <li>• Scoring (rating)</li> <li>• Comments</li> </ul>
AHP	<ul style="list-style-type: none"> <li>• Define the problem</li> <li>• Structure the criteria and sub-criteria hierarchy</li> <li>• Construct pairwise comparison of criteria in reaching the goal to determine the relative weight or priority of each criteria (sub-criteria)</li> <li>• Construct pairwise comparison of alternatives and score the alternatives compared under each criteria</li> <li>• Synthesize the comparative judgement and criteria weight to get the priority of each alternative with respect to the goal</li> </ul>
Delphi technique	<ul style="list-style-type: none"> <li>• Selection of a panel of experts</li> <li>• Questionnaire design</li> <li>• Repeating judgement</li> <li>• Revising judgement</li> </ul>
Evaluation matrix	<ul style="list-style-type: none"> <li>• Specify and prioritize evaluation criteria</li> <li>• Rating</li> <li>• Compare and select the best solution</li> </ul>
Kano model	<ul style="list-style-type: none"> <li>• Rate the satisfaction if the product has this attribute</li> <li>• Rate the satisfaction if the product does not have this attribute</li> </ul>
Kepner Tregoe matrix	<ul style="list-style-type: none"> <li>• Define requirements, objectives and limits</li> <li>• Rank objectives from the most to the least important and weight them</li> <li>• Generate alternative list</li> <li>• Score alternatives</li> <li>• Select top alternatives for in-depth examination in terms of potential problems and negative effect</li> </ul>

The existing scoring manners are mostly inclined to give a specified range (1-5, 1-7, and 1-9 are often used) as an ordinal or interval scale, and the evaluators need to give a crisp number or indicate a certain point to represent their ranking levels or scores. For example, the Likert scale (a representative ordinal rating scale) offers five ranking levels for the evaluators to rate. In fact, such rating methods contain hidden assumptions that 1) the evaluators could find their desired rating levels/scores among the offered options (especially for the ordinal scale), 2) the evaluators' opinions could be represented by a crisp number/a certain point (especially for the interval scale), and 3) the evaluators could make the decision of rating score without any hesitation. However, the three assumptions are impractical in reality, which implies that the existing rating manners actually neglect the three concerns. Therefore, an improved rating method is developed to handle these problems.

Assume that there are  $n$  design alternatives to be evaluated. They are denoted as an alternative set:

$$A = \{a_1, a_2, \dots, a_i, \dots, a_n\}, \quad (i = 1, 2, \dots, n)$$

Assume that there are  $m$  evaluation factors in total.  $m^c$  cognitive evaluation factors, and  $m^e$  affective evaluation factors.

$$F = \{f_1, f_2, \dots, f_j, \dots, f_m\}, \quad (j = 1, 2, \dots, m)$$

$$m = m^c + m^e$$

According to these evaluation factors, the extent to which these design alternatives satisfy the evaluation factors is assessed. To allow the evaluators greater freedom to make assessments with uncertainties, the rating method should tolerate uncertainties and fuzziness. Therefore, interval numbers with higher tolerance for uncertainty are considered to allow the evaluators to freely outline their assessment. However, most of the numerical methods for interval numbers (e.g., Dempster–Shafer theory) require exact distribution information (Sevastianov, 2007), which is not applicable in innovation assessment. Therefore, grey numbers—which have been identified to have the power to process interval data with unknown/uncertain distribution information—are used.

In general, a grey number is “*such a number whose exact value is unknown but a range within that the value lies is known.*” (Liu and Lin, 2006) In applications, a grey number is an interval or a general set of numbers. Let  $x$  denote a real number. A grey number  $x(\otimes)$  is defined as an interval with a known lower bound  $\underline{x}$  and a known upper bound  $\bar{x}$  but unknown distribution information for  $x$  (Huang et al., 1997).

$$x(\otimes) \in (\underline{x}, \bar{x}), \underline{x} \leq \bar{x}$$

In some situations, the point with the highest possibility is known or expected to be pointed out. Therefore, a three-parameter interval grey number is proposed:

$$x(\otimes) \in (\underline{x}, \tilde{x}, \bar{x}), \underline{x} \leq \tilde{x} \leq \bar{x}$$

where  $\underline{x}$  is the lower limit,  $\bar{x}$  is the upper limit,  $\tilde{x}$  is the point with the most possibility

Compared to a general grey number, a three-parameter interval grey number adds one more parameter for specifying the interval, so that the uncertainty is relatively reduced. Moreover, the middle parameter can be specifically defined according to the design focus so that the three-parameter grey number enables a freer and more targeted analysis of the interval numbers. In applications,  $\tilde{x}$  is often treated as the center of gravity (COG).

Therefore, the evaluation result of design alternative  $i$  regarding evaluation factor  $j$  can be denoted as:

$$x_{ij}(\otimes) \in (\underline{x}_{ij}, \tilde{x}_{ij}, \bar{x}_{ij});$$

where  $\underline{x}_{ij}$  is the acceptable lower evaluation score limit,  $\bar{x}_{ij}$  is the acceptable upper evaluation score limit,  $\tilde{x}_{ij}$  is the value especially highlighted to be analyzed.

To calculate  $\tilde{x}_{ij}$ , the uncertain distribution information in the interval  $(\underline{x}, \bar{x})$  is explored and properly assumed. Zadeh (1973) argued that “*the key elements in human thinking are not numbers, but labels of fuzzy sets, that is classes of objects in which the transition from membership to non-membership is gradual rather than abrupt.*” This suggests that fuzzy logic, especially fuzzy membership function, might be a useful way to give a relatively reasonable outline of the distribution information for the interval generated by human assessment. Moreover, the successful application of fuzzy logic in many studies further demonstrates the power of fuzzy logic in dealing with uncertain, fuzzy and linguistic variables (Tsoukalas and Uhrig, 1996). Therefore, fuzzy logic is introduced in this study to assist in calculating  $\tilde{x}_{ij}$ .

In short, innovation evaluation is characterized by unavoidable uncertainty and fuzziness. To tackle these problems, an interval number that can deal with uncertain data and can offer a freer evaluation environment is adopted. Among the methods for dealing with interval numbers, grey theory (which allows unknown/uncertain interval distribution) could represent the realistic evaluation result better. Therefore, it is emphatically considered. To further study the fuzziness associated with the evaluation results, fuzzy sets are introduced. Therefore, a combination of these techniques might be the most suitable solution in this problem context.

Based on the preceding analysis, a fuzzy rating scale combined with grey numbers is proposed to assess ICPD in order to fully exploit grey numbers and fuzzy logic. Firstly, fuzzy sets with specified bounds are defined by experts. Referring to these fuzzy sets, fuzzy membership functions are designed along the rating range. Thus, an assessment with completely unknown interval information is improved, replacing it with an assessment referring to a reasonable outline of the distribution of the rating scale. On the other hand, it synergizes the visual analogue and intuitive reasoning so as to further enhance the confidence and reliability of the evaluators' judgments. Regarding the specific membership functions, the commonly used Trapezoid-Triangle membership functions are applied (Figure 6.1). The membership degree can be obtained using Equation 6.1.

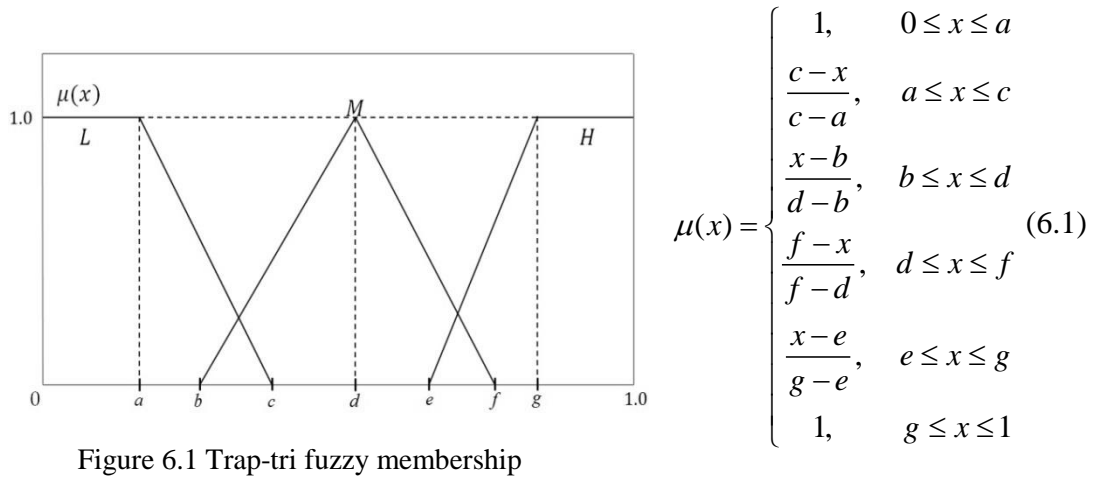


Figure 6.1 Trap-tri fuzzy membership

Based on the fuzzy sets, the evaluators can use general interval grey numbers to represent their assessment scores (by giving the acceptably largest and lowest assessment score). The third parameter can be defined as the COG of this interval and is calculated using Equation 6.2.

$$\tilde{x}_{ij} = \frac{\int_{\underline{x}_{ij}}^{\bar{x}_{ij}} \mu(x) x dx}{\int_{\underline{x}_{ij}}^{\bar{x}_{ij}} \mu(x) dx} \quad (6.2)$$

Once the middle parameter is obtained, the evaluation score matrices for cognitive factors  $x^c(\otimes)$  and emotional factors  $x^e(\otimes)$  could be denoted as:

$$x^c(\otimes) = \begin{bmatrix} x_{11}^c(\otimes) & x_{12}^c(\otimes) & \cdots & x_{1m^c}^c(\otimes) \\ x_{21}^c(\otimes) & x_{22}^c(\otimes) & \cdots & x_{2m^c}^c(\otimes) \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1}^c(\otimes) & x_{n2}^c(\otimes) & \cdots & x_{nm^c}^c(\otimes) \end{bmatrix}$$

$$x^e(\otimes) = \begin{bmatrix} x_{11}^e(\otimes) & x_{12}^e(\otimes) & \cdots & x_{1m^e}^e(\otimes) \\ x_{21}^e(\otimes) & x_{22}^e(\otimes) & \cdots & x_{2m^e}^e(\otimes) \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1}^e(\otimes) & x_{n2}^e(\otimes) & \cdots & x_{nm^e}^e(\otimes) \end{bmatrix}$$

Finally, the whole evaluation score matrix is obtained and can be denoted as:

$$X(\otimes) = [x^c(\otimes) \quad x^e(\otimes)] = \begin{bmatrix} x_{11}^c(\otimes) & x_{12}^c(\otimes) & \cdots & x_{1m^c}^c(\otimes) & x_{1(m^c+1)}^e(\otimes) & x_{1(m^c+2)}^e(\otimes) & \cdots & x_{1m}^e(\otimes) \\ x_{21}^c(\otimes) & x_{22}^c(\otimes) & \cdots & x_{2m^c}^c(\otimes) & x_{2(m^c+1)}^e(\otimes) & x_{2(m^c+2)}^e(\otimes) & \cdots & x_{2m}^e(\otimes) \\ \vdots & & & & & & & \vdots \\ x_{n1}^c(\otimes) & x_{n2}^c(\otimes) & \cdots & x_{nm^c}^c(\otimes) & x_{n(m^c+1)}^e(\otimes) & x_{n(m^c+2)}^e(\otimes) & \cdots & x_{nm}^e(\otimes) \end{bmatrix}$$

### 6.3.1.3 Design of weighting index

For the different evaluation factors, the design interests placed on them may be different; thus, a weighing process is necessary. Different weights are assigned to them according to their importance and priority.

$$\omega = \{\omega^c, \omega^e\}$$

$$\omega^c + \omega^e = 1 \tag{6.3}$$

For the cognitive evaluation factors, the weights need to be properly assigned:

$$\omega^c = \{\omega_1^c, \omega_2^c, \dots, \omega_{m^c}^c\}$$

$$\sum_{j=1}^{m^c} \omega_j^c = 1, \quad \omega_j^c \geq 0, \quad (j = 1, 2, \dots, m^c) \tag{6.4}$$

Similarly, a weight assignment process is performed for the affective evaluation factors:

$$\omega^e = \{\omega_1^e, \omega_2^e, \dots, \omega_{m^e}^e\}$$

$$\sum_{j=1}^{m^e} \omega_j^e = 1, \quad \omega_j^e \geq 0, \quad (j = 1, 2, \dots, m^e) \tag{6.5}$$

Regarding the weighting approach, three rounds of AHP are deployed for 1) prioritizing cognitive perspective and affective perspective; 2) weighting cognitive factors; and 3) weighting affective factors. The goal and evaluation factors could be organized into a hierarchy as shown in Figure 6.2.

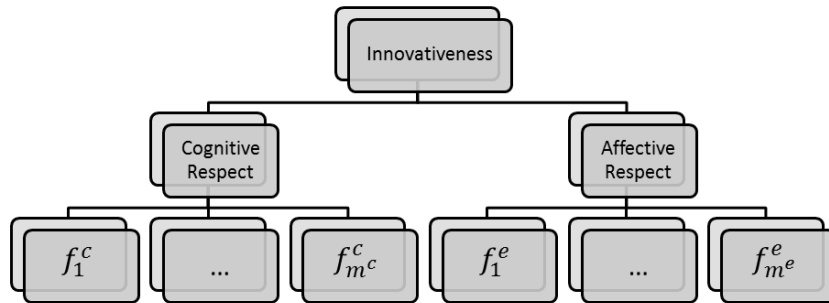


Figure 6.2 AHP for innovativeness evaluation factors

Basically, pairwise comparisons involving the compared nodes are required. The nodes at each level are compared two by two, with respect to their contribution to the nodes above them. That means, if there are  $n$  nodes,  $\frac{n(n-1)}{2}$  comparisons are needed. An example of the comparison between cognitive perspective and affective perspective in reaching the goal is given to illustrate the pairwise comparison. As shown in Table 6.3, two nodes of cognitive perspective and affective perspective are compared. For this comparison, the relatively weaker node is given a base weight of 1. For the other node, the fundamental AHP scale (1: Equal importance, 3: Moderate importance, 5: Strong importance, 7: Very strong importance, 9: Extreme importance) is used to define its weight compared to the base node. During this process, a detailed analysis or explanation is necessary to provide reference for supporting the weighting or prioritizing.

Table 6.3 Criteria compared with respect to reaching the goal

Node 1	Intensity	Node 2	Intensity
Cognitive innovativeness	3	Affective innovativeness	1
Comments			
<p>Cognitive respect provides the factors which could indicate innovation, and the evaluation on these items is not influenced too much by personal bias (e.g. evaluators' experience and knowledge), such as technology (i.e. whether any new technology (in recent 2 years) is applied); therefore, heavier weight should be assigned to strengthen the contribution of such hard innovativeness to the goal (i.e., general innovativeness). Affective respect provides the factors which could test emotional impact and the strength of such emotions; for innovativeness or newness, some opinions are tacit and hidden behind experts' intuitive reasoning; therefore, affective respect deserves to be studied separately, and such study could integrate the intangible knowledge and opinions into the innovativeness evaluation; compared with cognitive respect, affective respect is influenced by evaluators' attitude containing uncertainty and risk, and the weight should be relatively weaker with regard to the contribution of reaching the general innovativeness.</p>			

The results of these comparisons are organized into a weighting matrix that is processed mathematically to derive the priorities for all the nodes. For the example above,  $Node_{cog}$  to  $Node_{aff}$  is 3; thus,  $Node_{aff}$  to  $Node_{cog}$  is 1/3. The comparison results could be loaded in a matrix. An example of the weighting matrix of cognitive evaluation factors is presented in Table 6.4. The priority of each node is the principal right eigenvector of the matrix (Saaty, 2003). Assume that the calculated principal right eigenvector is  $v = (v_1, v_2, \dots, v_m)$ . The priority could be obtained as shown in Table 6.4.

Table 6.4 Weighting matrix of cognitive evaluation factors

Criteria	$f_1$	$f_2$	...	$f_{m^c}$	Priority
$f_1$	1	a	b	c	$\frac{v_1}{v_1 + v_2 + \dots + v_{m^c}}$
$f_2$	1/a	1	d	e	$\frac{v_2}{v_1 + v_2 + \dots + v_{m^c}}$
...	1/b	1/d	1	g	...
$f_{m^c}$	1/c	1/e	1/g	1	$\frac{v_{m^c}}{v_1 + v_2 + \dots + v_{m^c}}$
				Sum	1.000

### 6.3.2 Innovativeness estimation

Once the evaluation matrix is in place, the innovativeness of each design alternative will be estimated. Generally, the three-parameter interval grey numbers will be integrated to estimate the innovativeness. On the one hand, the evaluation results for different evaluation factors should be integrated; on the other hand, the three parameters of one evaluation score should be integrated. The ideal optimal and critical scores are defined, and the integrated evaluation scores are determined by comparing the raw evaluation scores with the ideal optimal and critical scores.

The ideal optimal and critical scores for each parameter are denoted as:

$$\underline{x}_j^+ = \max_{1 \leq i \leq n} \{\underline{x}_{ij}\} \quad \tilde{x}_j^+ = \max_{1 \leq i \leq n} \{\tilde{x}_{ij}\} \quad \bar{x}_j^+ = \max_{1 \leq i \leq n} \{\bar{x}_{ij}\} \quad (6.6)$$

$$\bar{x}_j^- = \min_{1 \leq i \leq n} \{\bar{x}_{ij}\} \quad \tilde{x}_j^- = \min_{1 \leq i \leq n} \{\tilde{x}_{ij}\} \quad \underline{x}_j^- = \min_{1 \leq i \leq n} \{\underline{x}_{ij}\}$$

The ideal optimal score is dimensioned with the optimal lower, middle, and upper scores, i.e.,  $\underline{x}_j^+$ ,  $\tilde{x}_j^+$ , and  $\bar{x}_j^+$ . Thus, the ideal optimal score for evaluation factor  $j$  would be denoted as  $x_j^+(\otimes)$ :

$$x_j^+(\otimes) \in (\underline{x}_j^+, \tilde{x}_j^+, \bar{x}_j^+)$$

The distance between the raw evaluation scores and the optimal one for each parameter can be denoted as:

$$\underline{D}_{ij} = |\underline{x}_j^+, x_{ij}| \quad \tilde{D}_{ij} = |\tilde{x}_j^+, \tilde{x}_{ij}| \quad \bar{D}_{ij} = |\bar{x}_j^+, \bar{x}_{ij}| \quad (6.7)$$

However, it is hard to judge whether or not the score is good based on only the absolute distance value. Therefore, the largest and smallest distances for each parameter are listed in order to provide reference for understanding the meaning of the distance better. This is denoted as:

$$\underline{D}_j^+ = \max_{1 \leq i \leq n} |\underline{x}_j^+, x_{ij}| \quad \underline{D}_j^- = \min_{1 \leq i \leq n} |\underline{x}_j^+, x_{ij}| \quad (6.8)$$

$$\tilde{D}_j^+ = \max_{1 \leq i \leq n} |\tilde{x}_j^+, \tilde{x}_{ij}| \quad \tilde{D}_j^- = \min_{1 \leq i \leq n} |\tilde{x}_j^+, \tilde{x}_{ij}|$$

$$\bar{D}_j^+ = \max_{1 \leq i \leq n} |\bar{x}_j^+, \bar{x}_{ij}| \quad \bar{D}_j^- = \min_{1 \leq i \leq n} |\bar{x}_j^+, \bar{x}_{ij}|$$

Normalized distances are used to integrate the three parameters. The rating score of design alternative  $i$  for emotional evaluation factor  $j$  can be calculated using Equation 6.9, where  $\partial \in [0,1]$  is a priority coefficient that can be set according to the preference between the upper and lower limits.

$$r_{ij} = \frac{1}{2} \left( (1-\partial) \frac{D_j^+ - D_{ij}^-}{D_j^+ - D_j^-} + \frac{\tilde{D}_j^+ - \tilde{D}_{ij}^-}{\tilde{D}_j^+ - \tilde{D}_j^-} + \partial \frac{\bar{D}_j^+ - \bar{D}_{ij}^-}{\bar{D}_j^+ - \bar{D}_j^-} \right) \quad (6.9)$$

$$r = \{r^c, r^e\} \quad (6.10)$$

Considering the usage of interval grey numbers, the uncertainties related to a large interval number and a small interval number are different. A larger interval indicates more uncertainties or hesitation during the evaluators' decision-making and increases the difficulty of making a right estimation. Therefore, the Greyness Index (*GI*) is proposed to reveal the degree of uncertainties.

$$GrI = \{GrI^c, GrI^e\} \quad (6.11)$$

However, the study of greyness relies on the domain of discourse of the grey variables (Deng, 1995; Liu, 1996; Yang, 2010). Therefore, an axiomatic system is developed to assist in the definition of the degree of greyness of the grey numbers.

Set:  $\Omega$  is the domain of discourse;  $u(\otimes)$  is the range of grey number  $x(\otimes)$ ;  $g^\circ(\otimes)$  is the degree of greyness. Then, a set of axioms is obtained:

Axiom 1:  $0 \leq g^\circ(\otimes) \leq 1$

Axiom 2:  $\otimes \in [a_1, a_2]$ ,  $a_1 \leq a_2$ , when  $a_1 = a_2$ ,  $g^\circ(\otimes) = 0$

Axiom 3:  $g^\circ(\Omega) = 1$

Axiom 4:  $g^\circ(\otimes)$  is proportional to  $u(\otimes)$ ; but inversely proportional to  $\mu(\Omega)$

Therefore, *GI* could be formulated using  $u(\otimes)$  (which can be calculated as  $|\bar{x}_{ij} - \underline{x}_{ij}|$ )

and  $u(\Omega)$  (which can be calculated as  $|\bar{x}_j^+ - \underline{x}_j^-|$ ), as in Equation 6.12.

$$GrI_{ij} = \frac{\bar{x}_{ij} - \underline{x}_{ij}}{\bar{x}_j^+ - \underline{x}_j^-}, \quad i = \{1, 2, \dots, n\}; \quad j = \{1, 2, \dots, m\} \quad (6.12)$$

Based on  $GI$ , an index of the degree of belief ( $BI$ ) is proposed to present the confidence of the evaluators about the assessment decisions. A larger  $GI$  indicates lower  $BI$ ; that is,  $BI$  has an inverse relationship with  $GI$  (Equation 6.13)

$$BI_{ij} = 1 - GrI_{ij}, \quad i = \{1, 2, \dots, n\}; \quad j = \{1, 2, \dots, m\} \quad (6.13)$$

$$BI = \{BI^c, BI^e\} \quad (6.14)$$

Cognitive innovativeness can be calculated by integrating the rating scores in each cognitive dimension with the consideration of the different weights of the different dimensions. The cognitive innovativeness ( $CI$ ) of design alternative  $i$  can be obtained using Equation 6.15.

$$CI_i = \sum_{j=1}^{m^c} r_{ij}^c \cdot BI_j^c \cdot \omega_j^c = \sum_{j=1}^{m^c} r_{ij}^c \cdot (1 - GrI_{ij}^c) \cdot \omega_j^c \quad (6.15)$$

Similarly, the emotional innovativeness ( $EI$ ) of design alternative  $i$  can be calculated by integrating the rating score in different dimensions:

$$EI_i = \sum_{j=1}^{m^e} r_{ij}^e \cdot BI_j^e \cdot \omega_j^e = \sum_{j=1}^{m^e} r_{ij}^e \cdot (1 - GrI_{ij}^e) \cdot \omega_j^e \quad (6.16)$$

In this stage, cognitive and emotional innovativeness are expected to be merged into one number that could reflect the design alternative's general innovativeness. Therefore, the general innovativeness of a design alternative  $GI_i$  can be achieved

by integrating cognitive and emotional innovativeness with the modification based on *BI*.

$$GI_i = CI_i \bullet \omega^c + EI_i \bullet \omega^e \quad (6.17)$$

## 6.4 Numerical illustration using a case study of future PC design

In this section, the proposed GF-CIEA is performed to further verify the promising concepts identified by AI-ICDP (in Chapter 5) in terms of innovativeness. Prior to the implementation of the proposed approach on these concepts, a validation of the proposed grey-based fuzzy algorithm is provided.

### 6.4.1 Preliminary validation of the proposed grey-based fuzzy algorithm

To validate the proposed GF-CIEA, an example of the carrier-borne machine from Luo and Wang (2012) is used. The main parameters are assumed to be the following six items: maximum speed ( $\mu_1$ ), freedom of the sea voyage ( $\mu_2$ ), maximum payload ( $\mu_3$ ), purchase cost ( $\mu_4$ ), reliability ( $\mu_5$ ), and flexibility ( $\mu_6$ ). There are four kinds of models to be evaluated as candidates. Hence, the factor set is  $U = \{\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6\}$ , and the candidate set is  $V = \{v_1, v_2, v_3, v_4\}$ . The normalization evaluation matrix of the interval grey numbers is as follows:

$$X(\otimes) = (x_{ij}(\otimes))_{4 \times 6} = \begin{bmatrix} (0.78, 0.85) & (0.50, 0.58) & (0.90, 0.95) & (0.80, 0.85) & (0.45, 0.57) & (0.90, 0.97) \\ (0.92, 1.00) & (0.95, 1.00) & (0.85, 0.88) & (0.65, 0.71) & (0.17, 0.23) & (0.47, 0.55) \\ (0.70, 0.78) & (0.72, 0.75) & (0.95, 1.00) & (0.94, 1.00) & (0.80, 0.85) & (0.80, 0.85) \\ (0.85, 0.90) & (0.65, 0.70) & (0.90, 0.96) & (0.85, 0.93) & (0.46, 0.52) & (0.48, 0.52) \end{bmatrix}$$

where  $x(\otimes) = (\underline{x}, \bar{x})$ ;  $\underline{x}$  is the lower limit; and  $\bar{x}$  is the upper limit.

Once the grey numbers are obtained, Equations 6.1 and 6.2 are used to calculate the interval centers  $\tilde{x}$ . A proper set of fuzzy membership functions should be deployed along the evaluation range. The commonly used combination of trap-tri fuzzy membership functions are adopted in this study, as presented in Figure 6.3.

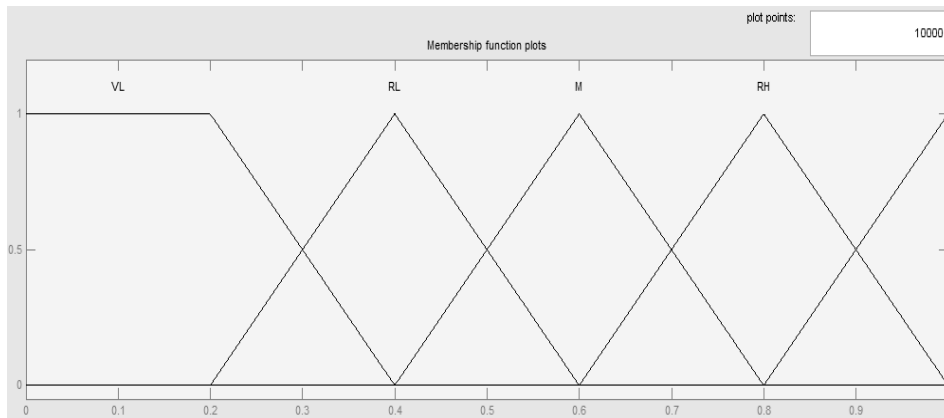


Figure 6.3 Fuzzy membership functions

The three-parameter grey numbers are attained in this manner.

$$X(\otimes) = \begin{bmatrix} (0.78, 0.81, 0.85) & (0.50, 0.54, 0.58) & (0.90, 0.93, 0.95) & (0.80, 0.82, 0.85) & (0.45, 0.51, 0.57) & (0.90, 0.94, 0.97) \\ (0.92, 0.96, 1.00) & (0.95, 0.98, 1.00) & (0.85, 0.86, 0.88) & (0.65, 0.68, 0.71) & (0.17, 0.20, 0.23) & (0.47, 0.51, 0.55) \\ (0.70, 0.74, 0.78) & (0.72, 0.74, 0.75) & (0.95, 0.98, 1.00) & (0.94, 0.97, 1.00) & (0.80, 0.82, 0.85) & (0.80, 0.82, 0.85) \\ (0.85, 0.87, 0.90) & (0.65, 0.67, 0.70) & (0.90, 0.93, 0.96) & (0.85, 0.89, 0.93) & (0.46, 0.49, 0.52) & (0.48, 0.50, 0.52) \end{bmatrix}$$

According to Equation 6.9,  $r_{ij}^e$  could be calculated:

$$\begin{bmatrix} 0.329 & 0 & 0.549 & 0.498 & 0.499 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0.030 \\ 0 & 0.445 & 1 & 1 & 1 & 0.745 \\ 0.602 & 0.305 & 0.596 & 0.720 & 0.464 & 0.006 \end{bmatrix}$$

According to Equation 6.12,  $GI_{ij}$  could also be calculated:

$$\begin{bmatrix} 0.233 & 0.160 & 0.333 & 0.143 & 0.176 & 0.140 \\ 0.267 & 0.100 & 0.200 & 0.171 & 0.088 & 0.160 \\ 0.733 & 0.940 & 0.667 & 0.829 & 0.926 & 0.900 \\ 0.833 & 0.900 & 0.600 & 0.771 & 0.912 & 0.920 \end{bmatrix}$$

To calculate the general innovativeness, the weights of the different parameters should be properly assigned. In this example, a set of normalized weight vectors is given as:

$$w = \{w_1, w_2, w_3, w_4, w_5, w_6\} = \{0.17, 0.12, 0.13, 0.13, 0.21, 0.24\}$$

Once the weight vector has been obtained, the general innovativeness could be obtained through Equation 6.17.

$$GI = [0.396, 0.239, 0.497, 0.327]^{-1}$$

It could be reached that for these four candidates,  $v_3 > v_1 > v_4 > v_2$ .

Although the weight vector is given by some experts based on statistical analysis, unknown bias (e.g., personal bias, calculation model bias) might exist. In addition, the weight vector is specified for this particular case. It is hard to apply it in a broader use. To eliminate the influence caused by the weight vector, the commonly assumed equal weights are introduced:

$$w = \{w_1, w_2, w_3, w_4, w_5, w_6\} = \left\{ \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6} \right\}$$

Using this commonly adopted weight assumption, the final innovativeness could be calculated using Equation 6.17.

$$GI = [0.386, 0.276, 0.585, 0.353]^{-1}$$

The result still shows that for these four candidates,  $v_3 > v_1 > v_4 > v_2$ . Although the absolute values of the estimated innovativeness are different, the ranking of the candidates is consistent with the earlier result, as well as the final decision, i.e.,  $v_3$  is the best scheme. Therefore, it suggests that the influence of the weight vector is moderate, and that the final decision is acceptable and reliable.

Table 6.5 A summary of the different grey decision models

Methods	Input	Weighting	Distance formula	Results
(Luo and Wang, 2012; Dang and Wang, 2004)	Standardized three-parameter evaluation matrix	Index weight assigned based on estimation target; Corrected weights by an optimization model	Positive distance $r_{ij} = \sqrt{\frac{1}{3} \left\{ \sum_{j=1}^m w_j [(x_{ij} - \underline{x}_{ij}^+)^2 + (\tilde{x}_{ij} - \tilde{x}_{ij}^+)^2 + (\bar{x}_{ij} - \bar{x}_{ij}^+)^2] \right\}}$	$v_3 > v_1 > v_4 > v_2$
(Luo and Wang, 2012)	Standardized three-parameter evaluation matrix	Index weight assigned based on estimation target	Negative distance $r_{ij} = \sqrt{\frac{1}{3} \left\{ \sum_{j=1}^m w_j [(x_{ij} - \underline{x}_{ij}^-)^2 + (\tilde{x}_{ij} - \tilde{x}_{ij}^-)^2 + (\bar{x}_{ij} - \bar{x}_{ij}^-)^2] \right\}}$	$v_3 > v_1 > v_4 > v_2$
The proposed algorithm	Standardized two-parameter evaluation matrix; compute the interval center referring to fuzzy logic	Index weight assigned based on estimation target	Normalized distance $r_{ij}^g = \frac{1}{2} \left( (1-\delta) \frac{D_j^+ - D_{ij}}{D_j^+ - D_j^-} + \frac{\tilde{D}_j^+ - \tilde{D}_{ij}}{\tilde{D}_j^+ - \tilde{D}_j^-} + \delta \frac{\bar{D}_j^+ - \bar{D}_{ij}}{\bar{D}_j^+ - \bar{D}_j^-} \right)$	$v_3 > v_1 > v_4 > v_2$

The proposed method is compared with other grey decision models based on a similar set of evaluation matrix. Particularly, two typical models that adopt positive and negative distances, respectively, are considered. The differences between the proposed algorithm and the other techniques are summarized in Table 6.5.

A comparison with typical grey decision models indicates that the proposed algorithm could reach a consistent result effectively; therefore, from the algorithm perspective, the proposed approach appears to be useful to obtain a reliable decision. Therefore, the proposed approach is implemented on the Future PC Design case to further demonstrate the effectiveness of the proposed approach in dealing with the estimation of ICPD.

#### **6.4.2 Innovativeness estimation of the promising concept candidates**

The crowdsourcing design project of Future PC Design is used in this study. Through AI-ICDP, Concepts 1, 3, 4, 7, 9, 13, and 18 are identified as promising concepts and loaded in GF-CIEA to be further examined in terms of innovativeness.

##### ***6.4.2.1 An improved fuzzy rating system***

As discussed in Section 6.3.1.2, an improved rating system that is tolerant of fuzziness and uncertainty is required. Therefore, a computer-aided fuzzy rating system is developed to realize a fuzzy rating scale combined with grey numbers, as shown in Figure 6.4.

Generally, the 0-5 scale is set as the rating range. Interval grey numbers (with upper and lower limits  $(\underline{x}, \bar{x})$ ) are enabled as the interval evaluation score. To realize the rating using an interval number, two cursors are designed. One marks the acceptable maximum score, and the other marks the acceptable minimum rating score. Evaluators could freely move the cursors to give their desired rating interval. To reduce the blindness during the process of positioning the interval score, pre-specified fuzzy sets are presented along the rating range. Once the evaluators place the cursor at a certain point, the corresponding fuzzy set with the degree of membership is shown; e.g., this score is absolutely Low (100%), or this score is Relatively Low (40% L and 60% RL). Referring to this indication, the evaluators could have a clearer idea about their decision of the interval rating score. Further, the interval center  $\tilde{x}$  is calculated automatically and shown as a red arrow to further assist the evaluators to achieve a sober decision of the interval score. With the help of such visual analogue and intuitive reasoning, the rating process could be less blind and more evidential.

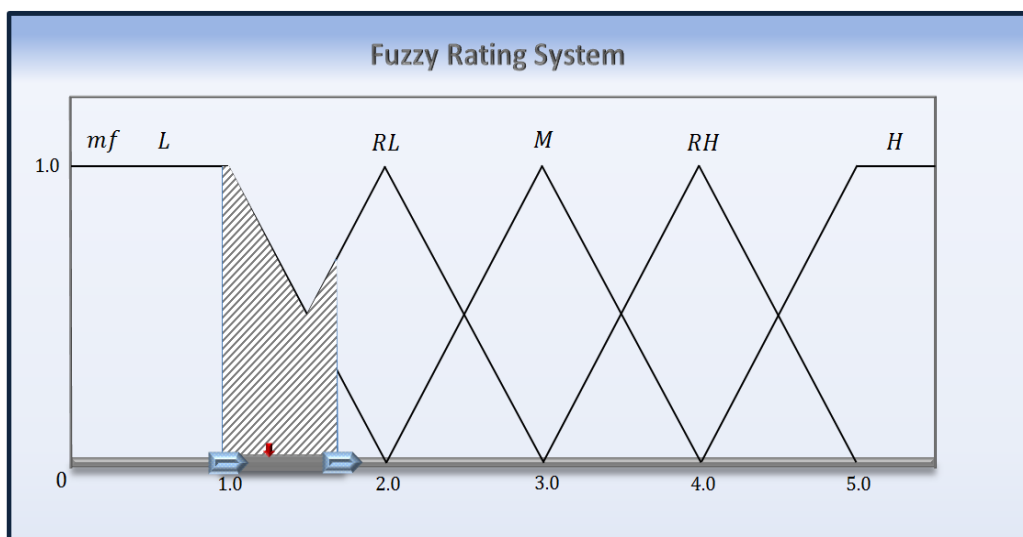


Figure 6.4 Fuzzy rating system

In summary, although complete freedom is given to enable the evaluators to give their original fuzzy and uncertain assessment, the clear interpretation of the interval information (in terms of the corresponding fuzzy set and the position of the interval center) induces the evaluators to be very rational and careful about their decision of the evaluation score; therefore, control over the free rating process is actually realized.

#### 6.4.2.2 Innovativeness estimation

Using the improved rating system, Concepts 1, 3, 4, 7, 9, 13, and 18 are reviewed and assessed according to the criteria presented in Table 6.1. Normalization evaluation results from a group of designers are collected and presented in Table 6.6.

Table 6.6 Evaluation results

Concepts		Cognitive Perspective							Affective Perspective		
		C1 Motivation		C2 Technology		C3 Functionality			E1 Attractive	E2 Unique	E3 Acceptable
		Q1.1	Q1.2	Q2.1	Q2.2	Q3.1	Q3.2	Q3.3			
1	$\underline{x}$	0.864	3.344	3.036	1.96	3.544	2.22	3.584	4.216	4.316	3.788
	$\bar{x}$	1.964	4.088	3.528	2.764	4.42	3.036	4.172	4.752	4.816	4.516
3	$\underline{x}$	1.792	3.092	2.176	0.944	1.28	2.764	1.92	3.248	3.248	3.368
	$\bar{x}$	2.512	3.788	2.704	1.444	1.792	3.4	2.508	4.032	3.648	3.944
4	$\underline{x}$	3.036	2.512	0.948	0.656	2.124	1.792	2.124	3.14	2.584	2.428
	$\bar{x}$	4.088	3.092	1.512	1.256	2.62	2.46	2.584	3.532	3.4	3.528
7	$\underline{x}$	1.712	1.608	2.348	2.348	2.88	2.388	1.792	2.088	2.32	2.852
	$\bar{x}$	2.388	2.356	3.22	3.092	3.5	3.204	2.348	3.024	3.22	3.868
9	$\underline{x}$	2.512	2.712	3.404	3.652	3.62	3.764	3.5	3.08	3.08	2.588
	$\bar{x}$	3.204	3.496	4.08	4.292	4.54	4.42	4.088	3.756	4.06	3.164
13	$\underline{x}$	2.572	3.092	3.704	3.332	3.832	2.896	1.812	3.036	3.544	3.832
	$\bar{x}$	3.5	3.916	4.292	4.088	4.4	3.684	2.512	3.908	4.088	4.6
18	$\underline{x}$	2.728	2.728	3.7	3.436	3.764	3.4	2.116	2.64	3.404	2.912
	$\bar{x}$	3.332	3.744	4.088	4.34	4.34	4.044	3.028	3.404	4.144	3.832

Referring to the improved fuzzy rating system, a set of Trap-Tri fuzzy membership functions could be generated, as listed in Equation 6.18.

$$u(x) = \begin{cases} 1, & 0 \leq x < 1 \\ 2 - x, & 1 \leq x < 2 \\ x - 1, & 1 < x \leq 2 \\ 3 - x, & 2 \leq x < 3 \\ x - 2, & 2 < x \leq 3 \\ 4 - x, & 3 \leq x < 4 \\ x - 3, & 3 < x \leq 4 \\ 5 - x, & 4 \leq x < 5 \\ x - 4, & 4 < x \leq 5 \end{cases} \quad (6.18)$$

With the help of Equations 6.18 and 6.2, the middle parameter  $\tilde{x}$  could be calculated, and the evaluation matrix with complete three-parameter grey numbers (7 candidates, 10 evaluation items) is obtained:

$$X(\otimes) = (x_{ij}(\otimes))_{7 \times 10} =$$

(0.864, 1.389, 1.964)	(3.344, 3.759, 4.088)	(3.036, 3.254, 3.528)	(1.96, 2.326, 2.764)	(3.544, 3.991, 4.42)
(1.792, 2.119, 2.512)	(3.092, 3.425, 3.788)	(2.176, 2.428, 2.704)	(0.944, 1.169, 1.444)	(1.28, 1.543, 1.792)
(3.036, 3.579, 4.088)	(2.512, 2.833, 3.092)	(0.948, 1.196, 1.512)	(0.656, 0.944, 1.256)	(2.124, 2.35, 2.62)
(1.712, 2.04, 2.388)	(1.608, 1.986, 2.356)	(2.348, 2.828, 3.22)	(2.348, 2.764, 3.092)	(2.88, 3.157, 3.5)
(2.512, 2.887, 3.204)	(2.712, 3.079, 3.496)	(3.404, 3.783, 4.08)	(3.652, 3.977, 4.292)	(3.62, 4.057, 4.54)
(2.572, 3.025, 3.5)	(3.092, 3.505, 3.916)	(3.704, 3.998, 4.292)	(3.332, 3.753, 4.088)	(3.832, 4.097, 4.4)
(2.728, 3.025, 3.332)	(2.728, 3.195, 3.744)	(3.7, 3.905, 4.088)	(3.436, 3.918, 4.34)	(3.764, 4.043, 4.34)
(2.22, 2.678, 3.036)	(3.584, 3.898, 4.172)	(4.216, 4.481, 4.752)	(4.316, 4.579, 4.816)	(3.788, 4.119, 4.516)
(2.764, 3.067, 3.4)	(1.92, 2.181, 2.508)	(3.248, 3.676, 4.032)	(3.248, 3.44, 3.648)	(3.368, 3.686, 3.944)
(1.792, 2.101, 2.46)	(2.124, 2.332, 2.584)	(3.14, 3.318, 3.532)	(2.584, 2.994, 3.4)	(2.428, 2.983, 3.528)
(2.388, 2.839, 3.204)	(1.792, 2.059, 2.348)	(2.088, 2.573, 3.024)	(2.32, 2.814, 3.22)	(2.852, 3.327, 3.868)
(3.764, 4.074, 4.42)	(3.5, 3.826, 4.088)	(3.08, 3.398, 3.756)	(3.08, 3.59, 4.06)	(2.588, 2.896, 3.164)
(2.896, 3.246, 3.684)	(1.812, 2.129, 2.512)	(3.036, 3.464, 3.908)	(3.544, 3.842, 4.088)	(3.832, 4.173, 4.6)
(3.4, 3.762, 4.044)	(2.116, 2.594, 3.028)	(2.64, 3.017, 3.404)	(3.404, 3.817, 4.144)	(2.912, 3.338, 3.832)

### 6.4.2.3 Results and analysis

Equations 6.6, 6.7, 6.8, and 6.9 are applied to calculate the normalized distance in order to integrate the three parameters into one normalized rating score. Equations 6.12 and 6.13 are applied to calculate the proposed greyness that is helpful in refining the rating score by integrating the concern of the interval uncertainty.

*Normalized Rating =*

0	1	0.738	0.459	0.940	0.274	1	1	1	0.956
0.338	0.826	0.438	0.076	0	0.488	0.073	0.571	0.361	0.612
1	0.475	0	0	0.316	0	0.153	0.392	0.112	0.097
0.296	0	0.572	0.590	0.628	0.357	0	0	0	0.367
0.678	0.632	0.915	0.996	0.971	1	0.957	0.439	0.447	0.028
0.751	0.867	1	0.916	0.987	0.586	0.044	0.473	0.580	1
0.749	0.703	0.965	0.972	0.965	0.827	0.284	0.236	0.565	0.376

*Greyness =*

0.341	0.3	0.147	0.237	0.269	0.311	0.247	0.201	0.200	0.335
0.223	0.281	0.158	0.147	0.157	0.242	0.247	0.294	0.160	0.265
0.326	0.234	0.169	0.177	0.152	0.254	0.193	0.147	0.327	0.506
0.210	0.301	0.261	0.219	0.190	0.311	0.234	0.351	0.361	0.468
0.215	0.316	0.202	0.188	0.282	0.250	0.247	0.254	0.393	0.265
0.288	0.332	0.176	0.223	0.174	0.300	0.294	0.327	0.218	0.354
0.187	0.410	0.116	0.266	0.177	0.245	0.383	0.287	0.296	0.424



To combine the scores in each dimension and each perspective, the weighting process is executed as explained in Section 6.3.1.3. In this case study, in order to improve the generality, the weights are not designed specifically for this design case, and equal weights are assigned to each dimension. For the two perspectives (cognitive vs. affective), a moderately heavier weight is assigned to cognitive perspective as shown in Table 6.3 in order to control the emotional effect during the innovation evaluation. Once the weights/priorities are assigned, General

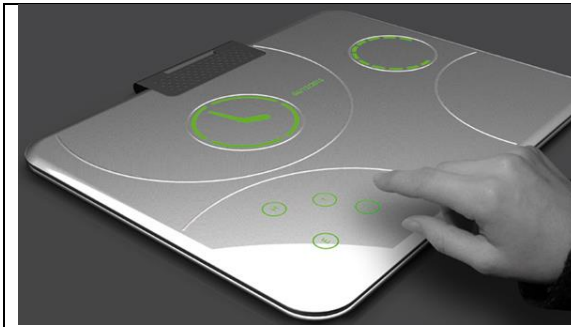
Innovativeness could be generated using Equations 6.15, 6.16, and 6.17. The result is as follows:

$$GI = [0.532, 0.293, 0.460, 0.219, 0.545, 0.554, 0.522]^{-1}$$

According to the result, Concepts 13, 9, and 1 are identified with leading advantage in terms of innovativeness. This result is different from the comprehensive ranking considering multiple objectives (e.g., user friendly, innovative, feasible) in Chapter 5. It is easy to understand that bold innovation is always not the safely optimal design solution. Although these concepts might not approach the optimal solution under various design considerations, they show highly impressive changes compared to other concepts in the conceptual design. In this regard, an in-depth examination is performed to summarize the innovative changes proposed in these concepts (Table 6.7), and these concepts with the impressive innovation points are considered for future use in similar design needs.

Table 6.7 A brief summary of the innovative changes

	<p><i>Concept 13:</i> This conceptual PC could enable simultaneous manipulation of PC and smartphone, so that they can support each other when necessary.</p>
	<p><i>Concept 9:</i> This conceptual PC enables different positions (e.g. sitting, lying), and is able to freely transfer data between different computers or smart devices.</p>



*Concept 1:*

This conceptual PC proposes a new kind of user interaction. Without opening the device, the user can check information on his/her PC-status or engage in online activities with friends in a very intuitive and poetic way. The two screens can be separated and used individually as tablet.

## 6.5 Chapter summary

In this chapter, an innovative product concept retention strategy is proposed to support the realization of CLRP. The core of this strategy is to identify the standard for the decision-making of concept retention (i.e., which concepts should be retained). As product innovation is an important way to obtain competitive products (refer to Chapter 2), innovativeness is considered an undoubtedly significant standard. The question of how to estimate the innovativeness of conceptual product design is raised. To tackle this problem, GF-CIEA is developed.

Primarily, ICPD (innovativeness of conceptual product design) is carefully defined using a multi-perspective and multi-attribute construct. Particularly, cognitive perspective and affective perspective are studied separately in order to reveal and properly manage the emotional effect in the innovation evaluation process. From each perspective, some factors that indicate the important influence on innovation effect are examined in depth to further concretize the ICPD. Since evaluation opinions are fuzzy and uncertain in nature, an improved rating method is specially developed to allow for uncertain interval inputs. To deal with such evaluation

results, fuzzy logic (especially for coping with fuzzy inputs) and grey theory (especially for handling uncertain interval data) are introduced. The innovativeness estimation algorithm is established based on a combination of these two theories. Once ICPD is elaborately defined, and the fuzziness and uncertainty in evaluation results are fully processed, the concepts with leading advantage in terms of innovativeness are expected to be identified.

To demonstrate the effectiveness of the grey-based fuzzy algorithm, a contrast study is performed. Using the same evaluation matrix, the proposed algorithm could achieve the consistent result with other typical grey decision models; therefore, the proposed algorithm appears to be effective to reach reliable results. The innovativeness estimation approach is executed on the promising concepts identified in Chapter 5, and three concepts with better performance in innovativeness are identified. Assisted by an in-depth concept analysis, the innovation points are further recognized, and these concepts are considered to be retained for potential use.

# Chapter 7 Conclusions and Future Research

## Research

Having introduced the position of the present research in the first chapter, the various stages of this work ranging from literature review to the application studies are documented from Chapters 2 to 6. Based on the discussions in the summary sections of the chapters, the conclusions arrived are summarized in Section 7.1. The limitations and potential avenues for advancing the research are presented in Section 7.2.

### 7.1 Conclusions

This thesis presents a product conceptualization strategy based on crowd-innovation (PCSCI) via creating a holistic crowdsourcing-based product conceptualization environment. In general, the crowd-innovation framework provides a strategic manner to construct product conceptualization process and is not limited to certain types of product. Products with physical features, such as personal computer, and products with intangible features, such as software, webpage, are all applicable for the proposed strategy. However, the complexity is varied by different product types. Particularly for complex engineering project, more cautious target analysis and task design is required, thus the computational capability and efficiency of the proposed strategy may be compromised.

Furthermore, the critical issues associated with crowdsourcing in each essential conceptual design process are studied in detail, and three prototype platforms are

constructed. They are the web-based knowledge acquisition platform (WKAP) where a systematic crowdsourcing platform for idea generation is established, the artificial intelligence-based innovative concept discovery platform (AI-ICDP) where an efficient and intelligent approach for dealing with crowdsourced conceptual designs is developed, and the concept learning and retention platform (CLRP) where an enhanced innovation assessment system is implemented.

In general, this research makes a pioneering contribution to the exploitation of crowdsourcing for supporting product innovation. Additionally, this work has gained research mileage in the field of computational intelligence for the management of crowdsourcing data and the processing of conceptual designs. With respect to the discussions presented from Chapters 2 to 6, this section highlights the original outcomes of this research.

### *A crowdsourcing platform development approach for concept generation*

The first PCSCI sub-system, i.e., WKAP, extends the conventional crowdsourcing conceptual scheme into a well-organized sophisticated crowdsourcing platform. It aims to provide a standard and systematic platform framing tool for facilitating the application of crowdsourcing in design practices. A prescriptive approach for developing a crowdsourcing platform is established. Three mechanisms to deal with the essential crowdsourcing elements, viz. target analysis, task design, and cheating control, are developed. From a general perspective, crowdsourcing is still a young concept. As such, the establishment of this crowdsourcing platform promotes the advancement of crowdsourcing studies. From a more specific

perspective, this approach makes original efforts in the quality control of crowdsourcing entries and the management of participation behaviors.

- 1) *A quality control scheme for crowdsourcing entries:* The major weakness of crowdsourcing is that the quality of entries is questionable. This is caused by the supervision dilemma in crowdsourcing process. To motivate participation, crowdsourcing is often deployed in a casual way. However, the low barriers of participation greatly increase the rate of trashy responses. Therefore, “effective participation” is proposed (refer to Chapter 2) to highlight that the value of crowdsourcing lies in valid contributions rather than in volume of participation. Thus, this research proposes an innovation target decomposition method and a neuro-fuzzy task allocation method to address this problem. Target decomposition provides a hierarchical target analysis procedure in order to drive assigners to give more consistent and explicit instructions. Further, the task allocation method converts the qualitative design requirements to quantitative standards, so that the most appropriate task type can be identified in a scientific and computational manner. In doing so, participation could be more directed, and the concern of blind participation can be eliminated. With the establishment of these two methods, a quality control scheme for crowdsourcing entries is realized.
- 2) *An active supervision measure for participation behaviors:* Participation behavior management in conventional crowdsourcing is powerless. Since the major motivation for crowdsourcing is monetary reward, the lack of supervision directly leads to cheating phenomena. However, few systematic and in-depth research efforts have been devoted to this field. A

cheating control mechanism is proposed in this research. With reference to the common causes of cheating, a set of cheating monitoring principles is identified. By embedding the verification questions and properly repeating and adjusting task allocation, the participants' performance could be verified using absolute standards; moreover, the quality of their contributions could be predicted. Thus, an active supervision measure for participation performance with the strategic arrangement of verification questions and the scientific identification of question types is obtained.

### *An effective concept evaluation and selection approach*

The second PCSCI sub-system, i.e., AI-ICDP, identifies a promising direction for tailoring computational intelligence in order to deal with conceptual designs. In fact, the integration of crowdsourcing in product conceptualization leads to the consolidation issues, such as a large number of designs to be processed, subjective and ambiguous conceptual designs, and crowdsourcing results in various formats. These concerns are interrelated, which increases the difficulty in processing crowdsourced conceptual designs. Therefore, an effective concept evaluation and selection approach in a crowdsourcing environment is developed to tackle these problems. Three processes, viz. a knowledge extraction process for capturing design information from the online crowdsourcing platform, a concept reconstruction process for unifying concept format, and a concept clustering process for simplifying decision-making, are strategically deployed. These processes contribute to an investigation of computational intelligence in dealing with conceptual designs and a new perspective of concept representation.

- 3) *Investigation of computational intelligence for dealing with conceptual designs:* This research directs an investigation of computational intelligence in the conceptual design field. In fact, the research trend of involving artificial intelligence in product design has been recognized, and some quantitative methods have been used to realize a preliminary intelligent design process. In the context of crowdsourcing, the computational intelligence techniques that are powerful in processing online qualitative data are emphatically explored to advance the research in this field. In particular, this research presents a web mining process to extract design knowledge from the online crowdsourcing platform, a text mining process to statistically analyze the qualitative design knowledge, and a clustering process to simplify concept comparison and decision-making. Further, necessary modifications and improvements to these techniques are developed; thus, in effect, this research contributes to an extended study of computational intelligence in the context of integrating crowdsourcing in product design.
- 4) *A new perspective of concept representation:* In crowdsourcing, the collected responses can be in various formats. The mixed formats lead to difficulties in mathematically analyzing the crowdsourced results. Therefore, the existing data processing methods for crowdsourcing are mainly qualitative analysis or basic statistical analysis. Advanced algorithms to deeply discover the indications from the crowdsourcing responses are scarce. This research presents a concept reconstruction method based on domain ontology and design knowledge hierarchy to

structure the crowdsourced design concepts into a unified format in order to improve the computability of crowdsourcing results. Thus, new perspective of concept representation is provided for facilitating concept analysis and processing.

*An innovativeness estimation approach for conceptual product design*

The third PCSCI sub-system, i.e., CLRP, sheds new light on an explorative study of innovativeness estimation for conceptual product designs. Referring to the prior efforts in this field, how to define innovativeness is still controversial, all the more so at the conceptual design stage where the design information is incomplete and ambiguous. Therefore, a clear definition of innovativeness of conceptual product design (ICPD) is still missing, which results in practical difficulties in innovation assessment (e.g., what the evaluation is based on). This research presents a multi-perspective and multi-attribute construct to define ICPD. By identifying the important facets in understanding product innovation, ICPD could be concretized and decomposed into specific attributes, such as new design motivation and new function. The identified attributes can be treated as innovation assessment standards, and they lay the foundation for an enhanced innovation evaluation method. Through an intensive study of ICPD, this research contributes to the innovation-oriented verification of conceptual designs.

5) *New definition of “innovativeness of conceptual product design” (ICPD):*

ICPD is carefully defined using a multi-perspective and multi-attribute construct. The important facets/factors in product design and innovation are examined in depth and identified as the dimensions or attributes to

concretize and delineate ICPD. In this study, the critical design concerns, viz. new design motivation, new technology, and new functionality, are highlighted as the indicators of product innovation. Additionally, expertise incorporation is necessary for innovation evaluation, especially in the conceptual design stage; therefore, personal bias as well as the emotional effect during the innovation evaluation is unavoidable (Cao, 2014; Desmet, 2012). Hence, an additional attitude test is proposed to refine the evaluation results and depict the tacit innovativeness. Therefore, two perspectives, a cognitive perspective covering the design concerns and an affective perspective offering an attitude test, are established. Thus, a well-constructed definition of ICPD is obtained.

- 6) *An innovation evaluation method with high tolerance for fuzziness and uncertainty:* Referring to existing evaluation systems, rating methods with fixed numerical levels as scoring options are widely adopted. However, evaluation opinions are fuzzy and uncertain in nature, and such rating methods greatly restrict the freedom of evaluators in giving their assessments. They may choose the closest option, which may not be the desired one. This research presents an improved rating method that enables fuzzy and interval rating scores. To deal with such evaluation results, fuzzy logic (especially for coping with fuzzy inputs) and grey theory (for handling uncertain interval data) are introduced. An innovativeness estimation algorithm is developed based on these two theories. Thus, an innovation evaluation method with high tolerance for fuzziness and uncertainty is realized.

In summary, this thesis aims to contribute to the creation of *a collective intelligence environment for product conceptualization* and the advancement of the *applications of computational intelligence in the conceptual design stage*.

## **7.2 Limitations and future research**

In this thesis, crowdsourcing is studied with the aim of fostering product innovation in the product conceptualization phase. Crowdsourcing, which is still a young concept, has not been experimented and studied comprehensively and systematically. Therefore, an elaborate development of the basic crowdsourcing scheme is worthwhile. The applications of crowdsourcing can potentially be extended to a wider range of problems. In this context, a crowdsourcing platform development approach is established. Further, computational intelligence is researched for dealing with the crowdsourced conceptual designs, and an enhanced innovation evaluation method based on fuzzy and grey theories is built. Nevertheless, limitations and constraints of the proposed PCSCI are inevitable as follows.

1. *Restrictions of existing crowdsourcing websites*: In this research, the basic crowdsourcing scheme is elaborately developed into a crowdsourcing platform. However, the development of such an online platform relies on crowdsourcing websites such as Mechanical Turk, where the task types and the interaction ways are actually fixed. The limited options for task design and arrangement restrict the crowdsourcing platform development from being more engaging and creative.

2. *Limited capability to deal with various concept formats:* Crowdsourced conceptual product designs are often presented using textual description and graphic models. Since the computability of textual information is higher, this study focuses on textual analysis and the processing of textual information. Image processing is defined as being beyond the scope of this study. From the perspective of understanding and handling the complete crowdsourced design information, the capability of the proposed concept screening and evaluation methods is limited.
3. *Unavoidable expertise incorporation:* The involvement of designers is necessary in product conceptualization. For concept evaluation and selection in particular, expertise is treated as a crucial input for decision-making. However, since it is a form of empirical knowledge based on previous experiments and experience, knowledge accuracy is questionable, and personal bias is inevitable. Thus, there is a dilemma: expertise is relatively subjective, but it cannot be replaced. Therefore, methods to handle the evaluation results should be carefully developed.
4. *Design concepts used for numerical illustration:* For each sub-system of the proposed PCSCI, a case study is presented for numerical illustration. As explained in Chapters 2 and 3, the major motivation for crowdsourcing is monetary reward; greater participation is costlier and more time-consuming. Therefore, the current case size is controlled at a medium level, i.e., 108 concepts for further filtering and analysis. To further verify the effectiveness of the proposed methods in a crowdsourcing environment, larger participation needs to be considered.

The research problems identified in this research are fundamental. Therefore, the results of this research may serve as references and foundations for future studies.

Four directions for future research are proposed:

1. *Further exploration of new crowdsourcing interaction modes:* This includes the development of new task types and new ways of task arrangement. The aim of this study is to make the current crowdsourcing platform more engaging and interactive.
2. *Improvement of concept analysis methods in a crowdsourcing environment:* The techniques used in dealing with crowdsourced conceptual designs can be continuously improved. In particular, the capability to handle multiple data formats simultaneously is required.
3. *Enhancement of concept evaluation methods in a crowdsourcing environment:* This includes two main points. The first is the enhancement of the current evaluation systems so as to better capture the full original evaluation opinions. The other is to enhance the data processing methods for handling evaluation results. The uncertainty and fuzziness related to subjective knowledge should be properly processed.
4. *Extending the experiment for greater participation:* When time and budget permit, larger participation could be considered. By experimenting with greater crowdsourcing responses, the effectiveness of the proposed PCSCI could be further verified. Moreover, the specific methods applied in each sub-system could be modified to make them more powerful in dealing with crowdsourcing data.

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# Appendix

Supporting materials are attached for a better understanding of this research.

## Appendix A – The PC Design Project on Designboom

### Appendix A.1 – Online crowdsourcing interface

#### A LIFE with Future Computing: LIFEBOOK category



#### A LIFE with Future Computing

with the spread of ICT, the ability for people to make diverse connections via networks with other people in all daily life situations have increased, through a variety of devices such as PCs and smart phones.

as a provider of ICT products and services, Fujitsu strives to create a new society that contributes to people's everyday lives. our aim is to make computing technology a familiar part of people's life so that it may be used conveniently by as many people as possible. this competition is held to make the future lifestyle of people richer and even more fun, and to give a concrete shape to the future as Fujitsu sees it by promoting the use of the ever-changing technology and dramatically expanding the possibilities of our services.

we will solicit new LIFEBOOK\* product designs targeted for 2013. applicants are reminded to think about possible situations where the PC may be used and to express the ideal next-generation computing device of the future as you see it.

the requirements are that it is a mobile device that can be carried around and that it can be operated through a network using computing technologies.

\* LIFEBOOK is Fujitsu's laptop PC series with the concept of Life Partner: - 'Always standing by your LIFE.'

LIFEBOOK's brand concept: the four values innovation:

Innovation: That it is innovative

Reliability: That it is highly reliable

Human Centric: That the design focuses on the user

Green: That it is friendly to the environment.

**You must allow Javascript to run on this page to complete this HIT**

What is your age

Under 17  17 - 24  25 - 29  30 - 34  Above 35

What is your gender

Male  Female

What is your occupation?

What is your annual income?

**2. explanation of ideas**

a brief description of your work that includes

the target users and value that the suggested product and service can provide to the users.

1. up to 3 files for uploading to designboom

(images or a composition of more images) of your project.

to upload your images please note: use only .gif, .jpeg, (72 dpi) max 150 kb each file, RGB color mode.

image size width: 600 pixels.

max image size height: max 800 pixels.

video clips: we accept flv or swf files only. file size: 640 pixels x 480 pixels - max 10MB.

the entry submitted is a low-res version of your original work.

these original high-resolution image(s)

and additional text

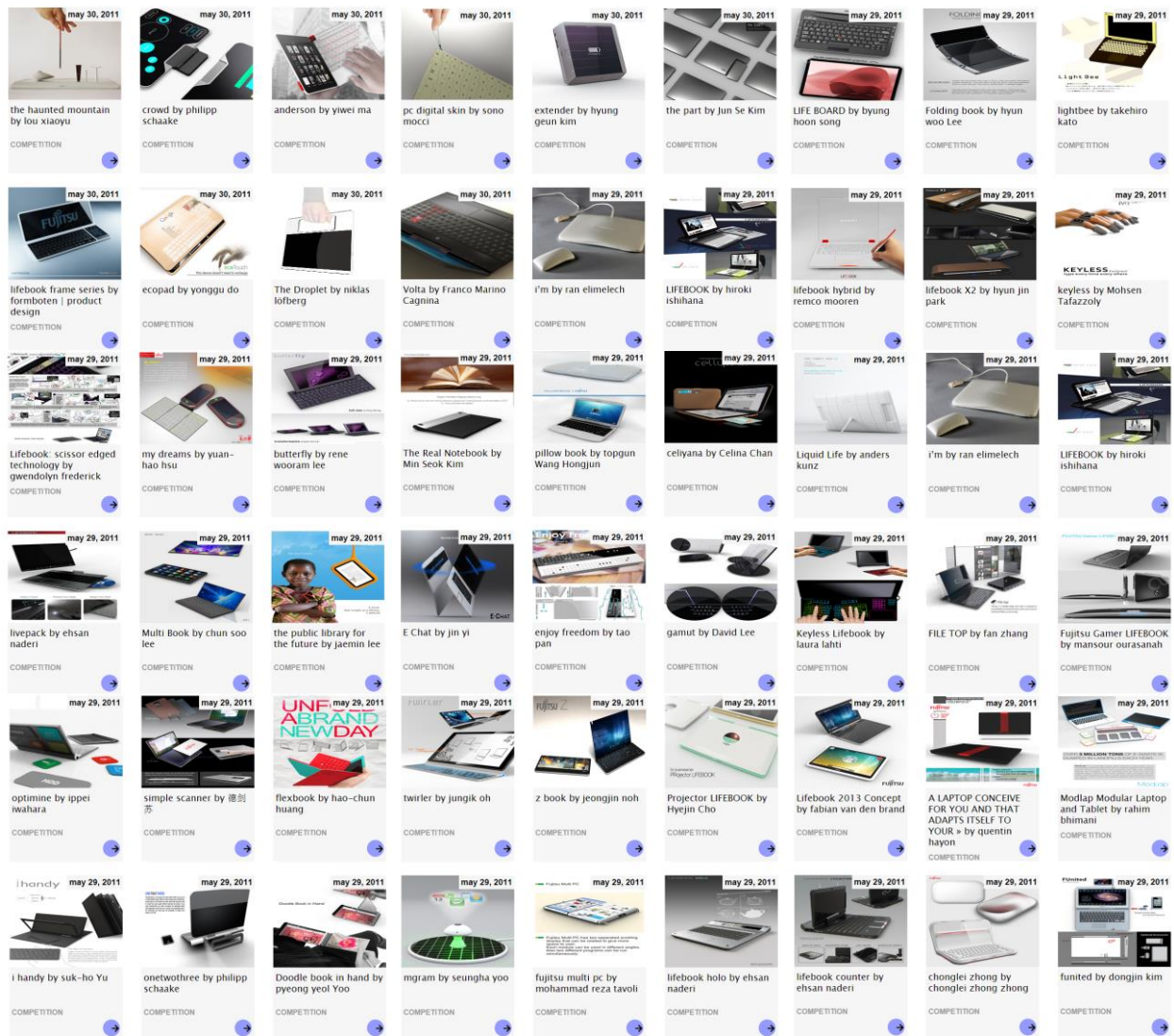
**3. you will be requested to accept the competition guidelines**

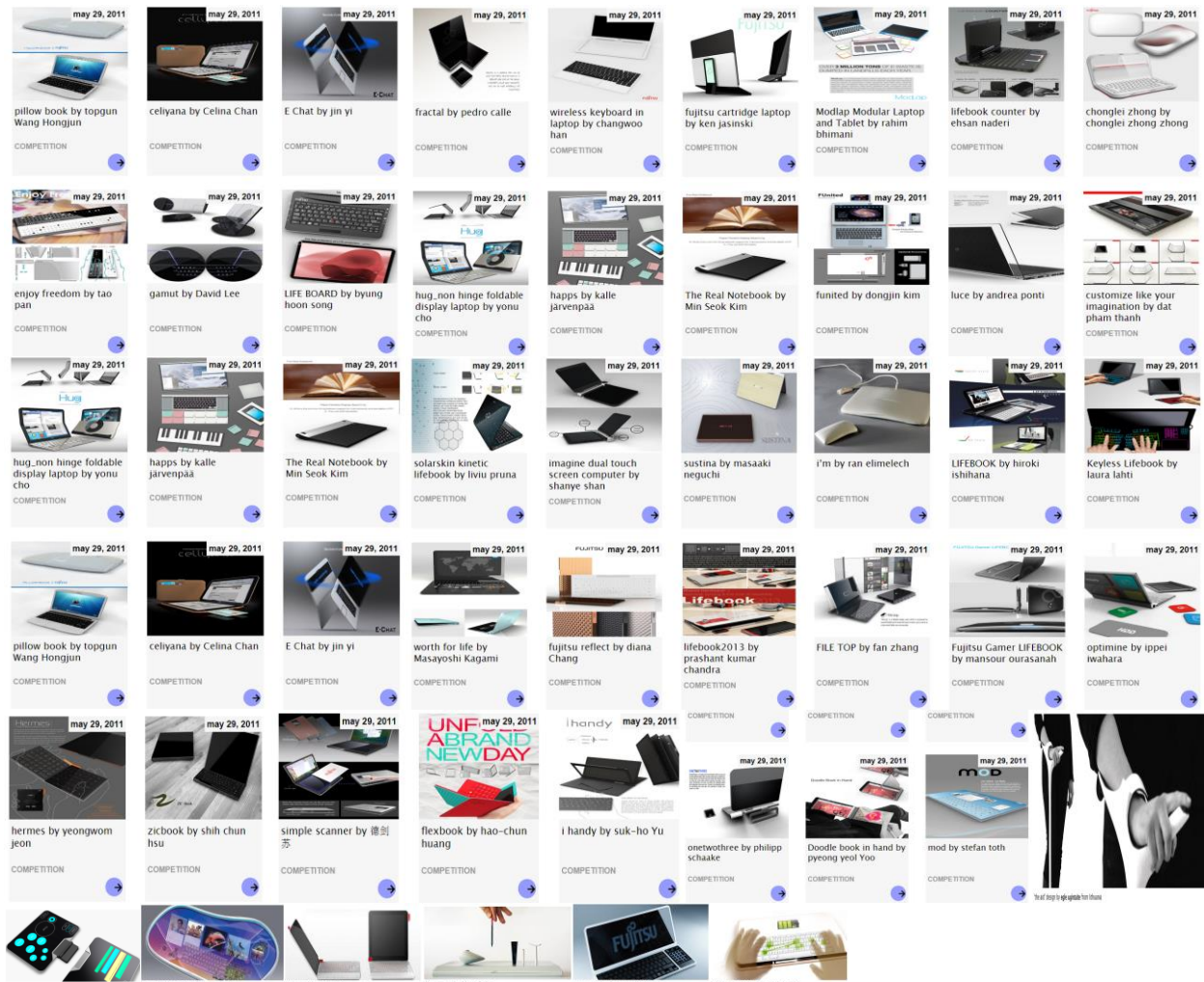
*submitted work must be original work by the applicant himself/herself that has never been released either in Japan or overseas. until the results of this award are announced, applicants are prohibited from entering the work in any other contests, or for publication elsewhere. entries that have violated the above conditions, or entries to which any of the following applies, shall be excluded from the list of entries to be screened.*

*furthermore, even after the award winners have been announced, the award may be cancelled if it is revealed that any of the following applies to the winning work.*

- works whose design is identical to, or closely resembles, designs that have already been released (including works that are identical to, or similar to, works developed by Fujitsu Limited)
  - works that have been entered in other contests, etc., in the past
  - works that are offensive to public order and morals, or works whose aim is defamation or profit-making
  - works that infringe the intellectual property rights or right to confidentiality of a third party (including cases where the infringement had occurred after the application was made).
- even if a third party claims infringement of rights or demands compensation for damage, etc., with regard to the submitted work, Fujitsu Limited and Fuji Design Ltd. shall assume no responsibility whatsoever.*

## Appendix A.2 – Crowdsourcing results

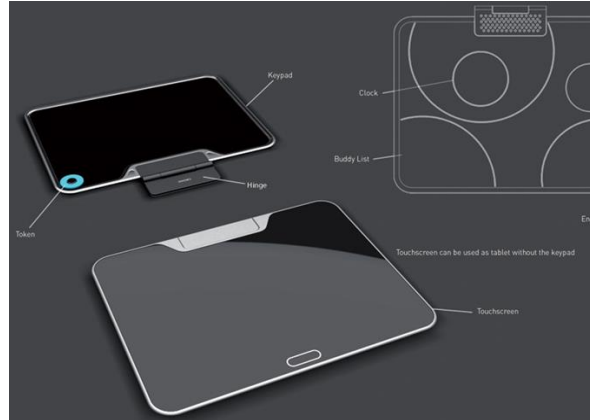




## Appendix A.3 – Details of crowdsourced conceptual designs (after filtering) used for further analysis

### Concept 1 - 'crowd' by Philipp Schaake



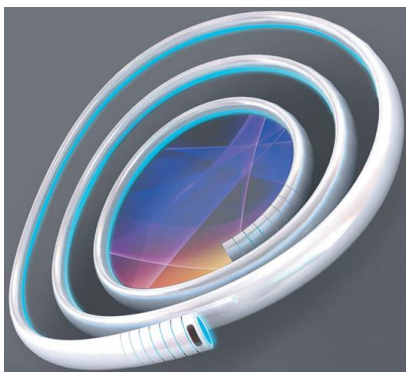


**Designer's own words:**

The computing concept 'crowd' wants to celebrate a new kind of interaction between the user and his / her PC without opening the device, the user can check information on his / her PC-status or engage in online activities with friends in a very intuitive and poetic way. on the one hand 'crowd' can be used like a typical laptop on the other hand the user can activate a new, playful and haptic interface for surfing the web, chatting or mailing.

Putting a token on the touchpad activates the 'interactive playground'. Depending on the mode, different sized avatars represent friends who are online or display a history of web-sites you have visited. The sizes of the avatars are determined by the frequency in which you have contacted a certain person or have entered certain website in the past. This interface provides the user with a very clear and graphically based overview of his recent online activities.

**Concept 2 - 'integral cord'** by Raphael Lang, Yu-lin Hou and Stephen Chan Win Tak



**Designer's own words:**

What if the display of your future Lifebook was as flexible as possible? With 'integral cord' you can easily manipulate your computer screen to your desired size and shape, making it adaptable to any working or social situation.

If you want to see your favorite movie on a small screen in the subway, or present your pictures to a large audience or if you need multiple screens at the same time, coil it! The technology involves beams of several LEDs overlap at a cross point and create a visible pixel.

An interface can be created by a multicolor laser LED array located on the inner side of the computer, and camera array can detect the position of the user's fingers.

### Concept 3 - 'Anderson' by Ma Yiwei and Tao Ying



#### Designer's own words:

'Anderson' is next-generation computing device with a compact square profile that is easy to carry and hold in hands. it is designed for people who always want to stay connected with the internet, no matter when or where they are two-way operating modes enable 'Anderson' to be

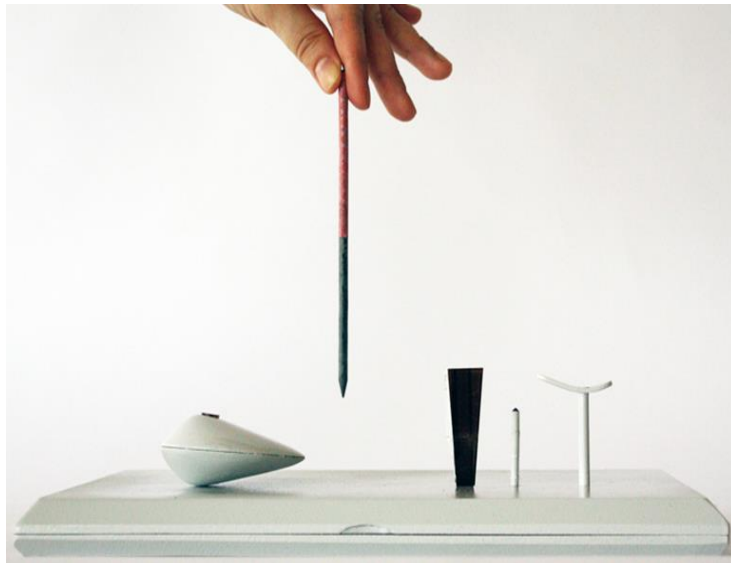
used in both 'static' and 'in-motion' situations. in landscape mode the device can be carried around while in use, in a manner similar to that of holding and reading a book sitting down to enjoy a coffee and surf internet 'Anderson' is best used in portrait mode.

Demonstration of 'landscape mode' (left) and 'portrait mode' (right)

In movement, 'Anderson' is best used in landscape mode and can be held much like a book

In static mode, 'Anderson' is best used in portrait mode and used like a laptop.

#### Concept 4 - 'The haunted mountain' by Lou Xiaoyu



#### Designer's own words:

Today, the international market proposes a range of digital products. Who crystalize all the values of our society, becoming the contents of knowledge and know-how. On the other hand, in a simple volume, we would like to combine all these possible functions. 'The haunted mountain'

acts as a ‘functional landscape’, transforming the computer into an informative, emotional, functional object strongly connected to our everyday life. The device provides a platform in which additional functions: a projector, light, aromatherapy stick, virus alerts, audio sensor... are added similar to that of an acupuncture method via these ‘pin-like’ components that are attached to the lid of your laptop. When not needed, they can be pulled out and stored separately from your computer.

Individual components and their size in comparison to a toy figurine.

The individual components are inserted into the lid of one’s laptop.

‘The haunted mountain’ used as a projector.

One component acts as a back light.

Standing as a beacon of light on your laptop.

Each element is simply inserted into a corresponding hole located on the lid of one’s laptop

The individual elements which can be attached to the lid of the computer.

### Concept 5 - ‘Lifebook frame series’ by Florian Langer + Patrick Decker



#### Designer’s own words:

Our lifebook design brings integrates individual capabilities of devices such as smart phones and slate terminals within a single computer. ‘lifebook frame series’ features an integrated and detachable multifunctional unit – the ‘lifegear’ device, and a clear structured frame-based layout which provides transparency over the assignment of technical components. easy maintenance is ensured by the keyboard’s clever substructure. within the lifebook, the lifegear serves as a number pad, touch pad, graphic tablet as well as a social network interface. when one is on-the-go, it can be used as a smartphone with handy data management.

## Concept 6 - 'Ecopad' by Yonggu Do + Jun-se Kim + Eun-ha Seo

Electricity is made automatically only by using your ECOPad



### Designer's own words:

Electricity is made automatically simply by using your 'ecopad'. currently commercialized tablet PCs and smart phones have a very limited battery life – often not more than a day before having to be recharged. on average, people press their touch screens over 10,000 times a day. the 'ecopad' does not require special charging from an adaptor. instead, it generates electricity when a user presses the touch screen due to the nano piezoelectricity film that is located below the display.

Electricity is generated when the user presses the touchscreen

## Concept 7 - lifebook hybrid by Remco Mooren from netherlands



### Designer's own words:

"My design combines the functionalities of a e-reader, tablet-PC and Netbook in a simple and innovative way. While similar devices have limited possibilities for input, the integrated

drawing-pad and included stylus support precise drawing or navigating. The E-ink display offers a pleasant reading experience or gives direct feedback while drawing or typing. The transparent display will give you the complete internet experience and supports all kinds of applications that support creative people in their everyday life.

The device contains a E-ink touch & drawing-pad to support your creative activities and a transparent display for a complete internet experience and use of applications.

The included stylus can also be used as a stand to support the LifeBook while watching a movie or to show some pictures. The E-ink screen turns black to preserve the colours of the shown content.

The E-ink screen gives the user a pleasant reading experience. The transparent screen can enhance this experience by adding extra information to the reading content. Off course the full functionality of the device is preserved in tablet mode.

#### **Concept 8 - Livepack by Ehsan Naderi from iran**



#### **Designer's own words:**

" -The design addresses people who want to replace their PC with high performance, ultra portable and barrier free internet access technology in business laptops market segment -The tablet can unhinge from the main high performance computer -The device runs with two operating system and two processor -3G and WiFi connection enables user to access to internet anywhere -Built in projector enables users to present their ideas -LED info panel shows received email and messages while the computer is standby -Thermoacoustic engine converts heat to electrical power -Brushed Metal and Allen screws give the notebook a modern and high

performance appearance

The tablet can unhinge from the main body

The Livepack addresses offline entertainment and business laptop market segment

-display: Multitouch OLED, 3D size: 14.3'', aspect ratio 16:9

-tablet processor: Intel CULV

-powerfull Intel main processor

-two operation systems for tablet and main body

-Multitouch Pad with LED backlit edge

-built in Thermoacoustic engine

-pressure sensitive stylus: with scroller, left and right click

-connectivity: 3G, Wifi, Bluetooth, wired broadband

-built in projector: brightness 30 Lm image size: 8''-50''

-camera: facial recognition instead of inger print recognition

-LED info panel shows received data while compututer is standby

-The design addresses people who want to replace their notebook with high performance, ultra portable and barrier free internet access technology in business and entertainment laptops market segment

-The tablet can unhinge from the main high performance computer

-The device runs with two operating system and two processor

-3G and Wifi connection enalbes user to access to Internet anywhere

-Built in projector enalbes users to present their ideas and to joy offline entertainment

-LED info panel shows received email and messages while the computer is standby

-Thermoacoustic engine converts heat to electrical power

-Brushed Metal and Allen screws give the notebook a modern and high performance appearance

**Concept 9** - Liquid Life by Anders Kunz from France



**Designer's own words:**

" When using computers throughout the day, two things are essential; 1) Having a flexible system that adapts to different needs and situations (e.g. work/pleasure, sitting/lying), and; 2) Being able to easily change data between different computers (e.g. from work computer to private computer).

The Fujitsu 'Liquid Life' ties the bits and pieces of our digital reality together. The slim stand of 'Liquid Life' does not only support the computer, it also saves changes in files and settings while the user works. When the user changes computer (s)he simply brings the stand to transfer files and settings wirelessly, allowing a fluid workflow.

Thanks to its touch screen, the 'Liquid Life' can be used as a tablet or laptop. The stand is magnetically fastened, making it possible to orientate the screen in any direction. A wireless keyboard can be taken out of the back. Its mouse pad is an empty space where IR-sensors triangulate the finger's position, giving the sensation of working in thin air.

**Concept 10 - i'm** by Ran Elimelech from Israel



**Designer's own words:**

" 'i'm' deals with the relationship between computer and it's user on a functional, emotional and

perceptual level. it answers the question why do we sometimes feel that our personal computer is our best friend, whom we can connect to and feel most comfortable with. the project divides this deep connection into three objects that embodies those levels: the core of connection, "i'm" or interfaced memory: a portable mouse that contains the computer's memory (with flash memory card) and functions as a proper hard-disk for the computer set with an interface that contains it. this i'm can be applied to other computers (with a sata cable) as a leech that uses their hardware as is own. the i'm allows the owner the possibility of a mobile personal work environment. the experience, the shell: light net-book that designed in a surface manner to enrich the emotional connection between the user and its computer. the connector: an input/output connector that contains usb, speakers, wi-fi and power plugs. this connector is exterior to the computer's body and can be disconnected without intemperance with the flow of the i'm experience.

### **Concept 11 - Fujitsu Gamer LIFEBOOK by Mansour Ourasanah from Usa**



#### **Designer's own words:**

" Computer gaming is a rapidly growing phenomenon among young people. The availability and ease of access to online and computer games has spawned a new generation of laptop users who have embraced the laptop as a gaming platform. The Fujitsu Gamer Lifebook is set to be released in 2013 as an-all-inclusive gaming laptop designed for computer gamers who are making the transition from gaming consoles to laptops. In 2013 The Gamer Lifebook will be introduced specifically for computer gamers with a need for a uniquely improved and forward-looking computer gaming experience. The main feature of the Gamer Lifebook is a removable touchpad that can be used as a video game controller and navigation pad for playing games where a

keyboard wouldn't be as comfortable. The functions of the controller can be activated by undocking it or using the on-screen activation features. The Gamer LIFEBOOK is also equipped with a high-resolution multimedia projector on the back of the screen. When activated, the projector will be used to provide the ultimate home theater screen size on walls or wall-mounted screens. This projection feature should appeal to users looking for a more immersive gaming experience without the need to purchase a projector. When closed, the Gamer LIFEBOOK functions and looks like a set-top box (STB) for streaming video games. The form factor of the laptop (sleek, curved, and ink-black) has been inspired by video game aesthetics with a hint of minimalism.

**Concept 12** - Flexbook by Hao-chun Huang from Taiwan



**Designer's own words:**

" "FLEXBOOK" is targeting the urban youth who's always connected with social networks. It could easily transform itself when consuming the contents with the most appropriate form. Thanks to the thin and flexible touch screen technology, it can be folded into smaller footprint. A size like a small novel can easily fit in any bags or pockets. Without using painting or fancy finishing, the rubberized exterior is truly eco friendly. Youth can customize their laptop with colors and in-mold 3D pattern when purchase online. Seamless keypad is water-proof and washable. Enjoy your favorite snacks and drink while using the laptop with no worries at all. Simply rotate and flatten the screen, it becomes an ultimate fun tablet. 21:9 screen and slim

stereo sound provides the best mobile entertainment for online movies, or video games with touch GUI on sides. When consuming the web contents, it's just so comfortable with a real scale viewing experience with the screen. Or if you are on a crowded transportation, it could literally fold into a handbook shape held by one hand only. Angled screen is the most natural way for reading and also gives you more privacy when sending text to your love ones :P  
"FLEXBOOK" is an intimate and expressive digital accessory that perfectly fits the youth lifestyle. It changes with you.

**Concept 13** - Lifebook AiO by Alex Ho from USA



**Designer's own words:**

" Most people already have mobile phone, then why buy a laptop when phone works like mini full-function computer? Connect Lifebook AiO (All-in-One) with ANY smartphone and you have tablet computer. Inspired by curve detail in Fujitsu logo, Lifebook AiO looks like an unrolled electronic paper scroll. SYNCing phone data with computer is imperfect and a waste of time, Lifebook AiO saves time by using one device - the phone, everywhere. No need to worry about software, all taken care off by phone company. Keep using LifeBook AiO even if phone becomes obsolete, then just change the phone!

Computer manufacturing has now become a capital-intense, low-margin business because of global competition. Rather than cutting costs, and thus profit, by trying to out-produce other manufacturers, Fujitsu should "turn the table" by having a product that could take ADVANTAGE of all the other computer and phone companies. Fujitsu's new LifeBook AiO would merge the computers and smartphones to enhance customers' experience using any communication device.

**Concept 14** - Fujitsu Life Bag by Ilian Milinov from Bulgaria



**Designer's own words:**

" Fujitsu Life Bag is a touch screen tablet pc which you don't need to take out of your bag because it is the bag. It is designed with the idea to be in the close proximity of the user and ready for use in any moment – during travel, walking, sitting, shopping. The main idea is to avoid the so boring preparation, opening of the bag, taking out the device, opening of the skin, taking it out of the skin, opening the device and at the same time wondering where to put your bag. I'm tired of hi-tech looking gadgets. Fujitsu Life Bag has a non digital look. Eco materials are used- woollen fabric and wooden edges. All the ports are inside the bag protected by waterproof membrane. Anti-shock flexible LCD display with torsion resistance and polymer antiscratch cover, it is visible all the time and thus it could be used as a fashion element of your outfit.

**Concept 15** - Tray by Robert Swinton from USA



### Designer's own words:

" TRAY is a simple personal computer that contains wireless keyboard, touchpad and wireless flash memory. A slot in the base allows for multiple screens and devices to be used and synced together in an understandable way. The base is embedded with magnets that hold the wireless screen on when in transport and aligns the other devices for the user's optimum ergonomic configuration. Wood is a beautiful material statement that recognizes our society's preference to use naturally renewable resources when possible.

Magnets align and hold the screen tight against the base while in transport. Magnets also hold the removable keyboard, touchpad and flash memory in place when mobile and when configuring for use.

Devices SYNC when placed in the tray slot together. Shared graphics seamlessly communicate the connection between the two screens and can save data to the memory pellet.

SYNC – Devices SYNC when placed in the tray slot together. Shared graphics seamlessly communicate the connection between the two screens and can save data to the memory pellet.

Mobility – The tray slot doubles as a slot for the shoulder strap. The strap is removed when the screen is taken off. A felt bottom cushions the device against the users body.

Entertainment – An external cinema display can be placed in the tray. The wood base can be rotated 180 degrees to hide the rest of the product to lessen distraction while viewing.

Ergonomics – The keyboard, Touch-pad and memory are held in place by a network of magnets

inside the base. These input devices can be placed anywhere to optimize comfort.

### Concept 16 - Customize like your imagination by Dat Pham Thanh from Vietnam



#### Designer's own words:

- At present, computer users require a computer to satisfy all the demand for jobs, entertainment, research, creative. But it must be compact, sturdy so you can easily carry and even use at all times in all circumstances, situations.
- Let 's imagine a computer that has the ability to customize the size and form to bring experience and explore entirely new for users' needs.
- A computer is equipped with three touch-screens: a foldable flexible screen and two against scratches screens on the surface of the computer.
- An outstanding idea: Computer is calculated detailed design and size according to needs, space and use situation, seach person can completely customize to have a different computer with form and reasonable aspect ratio so that most comfort and convenience with their individual when manipulate in the interface of software applications.

### Concept 17 - Split by Dae Hoon Jung from Korea



### Designer's own words:

" What are the most uncomfortable things when using a laptop? Probably it is the unsuitable size and weight of the laptop. Due to the improvement of a network system, most of the devices offer suitable user environment. This concept configures just like the well organized student supplies set. Users can take out the things that they need and use, such as; mouse, keyboard, monitor, pen, and etc. Taking out the big hinge, this laptop looks more like a book. By unifying the product and case (pouch), not only the case protects the product it also helps in the user interface because the pouch allows to adjust the angle of the screen and supports at the same time. Users can use all the devices in variety of user scenario. When the laptop is in a bag the user can control the laptop by using a remote control.

Taking out the big hinge, this laptop looks more like a book. By unifying the product and case (pouch), not only the case protects the product, it also helps in the user interface because the pouch allows to adjust the angle of the screen and supports the angle of the screen and supports at the same time. Users can use all the devices in variety of user scenario.

Remote control – When the laptop is in a bag the user can control the laptop by using a remote control. Thus, the hard device acts like a data base and user can use remote control to listen to

music and do simple things and such.

Users can take out the monitor and use it as tablet PC. And users can watch E-book and the remote (pen) helps study.

### **Concept 18** - Nesting PC Virtual Tablet by Sono Mocchi from Japan



#### **Designer's own words:**

"Today we have various types of computer interface. PC Laptop, mobile and smartphone, bookraeder. The diversity is a symbol of affluence but they have many same functions. Aren't they complicated ? The project progress to valuable functions and Integrate their meaning. Nnesting pc virtual tablet have a dock of mobile phone. When user slot it into the tablet, It monitor synchronize vision of mobile phone on the tablet. You can control mobile phone on nesting pc virtual tablet, dialing calling, mailing every operating method is same. They are visualization of your intuition. The interface on the interface ...like layers and transparency. It is a nesting structure of digital vision. Moreover loading out or in of optical disk media ,inserting of pen device,connection of USB port.Every phenomena is visualize on tablet LCD image and when you touch it, will work as real. You do not need looking for AC adapter of mobile phone. Because battery charging,data link saving are automatic. Nesting PC tablet is shortcut of your sense and feel. It aim to be interface near our life more and to future. Dimension and Spec - 13inch multitouch display laptop pc tablet/335mm,200mm,14mm, mobile phone/110mm,47mm,8mm

### **Concept 19** - Plus by Min Chia Lu from Taiwan



**Designer's own words:**

" Most people use laptop for internet, some people have lots of computer with different size. Sometimes we have too many product which have the same function.

If we can change the weight & function of laptop. we may have a better life and less waste.

"PLUS" is a notebook you can easy to add the function with the device brick no matter it is mini projector or extra battery . You can choose the brick according to your using habits.

The function brick of "PLUS" is easy to take apart and make up. For that reason you can change your laptop function and color everyday and it depends on your needed. Just like the toy brick use the favorite to build what we love.

**Concept 20** - Plantbook by Seung Gi Baek from Korea



**Designer's own words:**

" 1.Human cannot be above nature and only humans can live together, interacting on each other in nature. How are you trying to reduce CO2 emissions, facing fearful facts like global warming and climate change? PLATEBOOK is for normal people of the future society that will be worried a lot about gradually increasing CO2 emissions. Using this PLANTBOOK, users can naturally make discharge of oxygen a part of their lives. This is for human living in nature.

2.'PLANTBOOK' motivated by a bamboo is an environment-friendly design which charges a battery and discharges oxygen under water at the same time. It is based on a concept, "Nature is the best design'. As a system using the external water tank, not the internal water tank, PLANTBOOK continuously absorbs water when soaking it in water and water absorbed generates electrolysis using power stored in a solar heat plate installed on the top. In this process, it is operated using hydrogen as an energy source and discharging oxygen. If you put it into a water bottle while you don't use a laptop, it automatically charges a battery and discharges oxygen. A leaf-shaped strap hanging on the top is made with silicon. It plays a role of a hand ring and a green LED sharpens as a battery is charged. Using this LED, users can check how much spare capacity the batter has.

**Concept 21** - Fit by Gun-woong Kim from Korea



**Designer's own words:**

" Why do we have to purchase a Tablet PC and a Smart Phone separately? With the recent development of smart phone technology, specification of a smart phone is expected to outweigh the one of laptop by 2013. If so, is it true that we do not need a bulky tablet PC any more? Absolutely no. Smart phones and tablet PCs can be used depending on their own different purposes. User also can use them differently. For example, with a wide touch screen, a tablet PC is fit for experiencing entertainment such as watching movies, getting education, and surfing on the web. But it is true that making telephonic communication via the device and carrying it for a portable purpose are inconvenient. On the contrary, a smart phone has excellent features in terms of communications and portability, while offering inconvenient services for surfing on the web and watching movies due to its small-sized screen. 'FIT', a product combining the features of tablet PC and smart phones, complement such weak points. By attaching or detaching a smart phone to/from a tablet PC, Touchpad Module strengthened the elements of entertainment in smart phones, playing a role as an accessory. Users can properly select an environment that they want, and easily use the device. In addition, separating Bluetooth module from a smart phone, you can readily make telephone communication.

Smart phones and tablet PCs can be used depending on their own different purposes. User also can use them differently. For example, with a wide touch screen, a tablet PC is fit for experiencing entertainment such as watching movies, getting education, and surfing on the web. But it is true that making telephonic communication via the device and carrying it for a portable purpose are inconvenient. On the contrary, a smart phone has excellent features in terms of communications and portability, while offering inconvenient services for surfing on the web and

watching movies due to its small-sized screen.

#### Specification

-10.1 inch Touch screen

-Quad core CPU/2Ghz

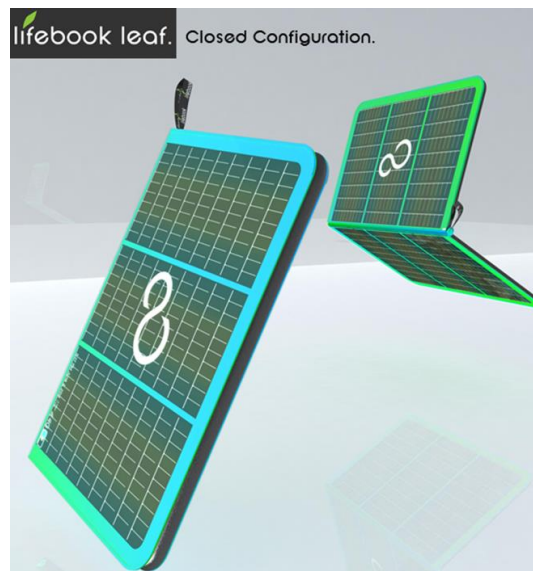
-8G memory

-10 mega pixel camera

-Bluetooth

‘FIT’, a product combining the features of tablet PC and smart phones, complements such weak points.

#### Concept 22 - LifeBookLeaf by Carl Burdick from USA



#### Designer's own words:

" With our collective environmental crisis beginning to spiral out of control, designers can no longer design products which rely on energy and resources as if those things were limitless. The LifeBook Leaf is an attempt to deal with these realities by Utilizing recent advances in amorphosis solar cells, flexible OLED displays, and advanced durable materials to create a highly efficient, solar powered Laptop which is totally divorced from the infrastructures of the past. The Leaf is designed to be highly durable to the extreme. Utilizing a polycarbonate exterior shell, the device is closed by the use of a waterproof zipper, much like those used in dry suits, which allow the Leaf to carried outside in the rain, without the typical worries of a electronic device. Along with a completely sealed body, this eliminates one of the most common causes of

failures among laptops: water damage. The interior of the laptop is one continuous touch screen, which can be utilized either in conventional mode, or as a tablet/wide screen display for media viewing. A head unit above the screen utilizes 3 small cameras for both 3d photography, as well as depth sensing for gesture based control of the user interface. When changing is needed, the Leaf spreads flat, and is turned upside down. A rubberized interior prevents scratching of the screen material inside, and a 4g module inside the device, along with a small transparent OLED display alerts the users if messages or alerts are received during charging. The high efficiency of both new CPU's, as well as Solar Cells allows the Leaf to also charge smaller mobile devices via USB at the same time.

LifeBookLeaf, Being Charged by the Sun.

LifeBookLeaf, Flexible Oled Touchscreen.

**Concept 23** - Celiyana by Celina Chan from China



**Designer's own words:**

"As per the rapid growing of information technology, time is priceless, online shopping or making transaction online with just one click is such a trend. With the emerge of internet, online shopper can look for and buy items they want that they cannot find in existed market, therefore, the burgeoning popularity and population of online shopping is a truly global phenomenon. Here we introduce our clutch bag like laptop, not only provide a faster, better, safer online shopping experience for regular online shopper, but also great for those who never tried or not yet find the ease of internet shopping.

Credit card, with no doubt, a popular tool for payment today, seems everyone already have

several credit cards, it is also by far the most common way of making transaction for online purchases, in order to push this further, we designed a laptop with a new system of purchase, you can simply insert a credit card inside the slot equipped and sign to finish a payment process, to give shopper a more convenience and time saving shopping experience ever. With this new laptop, you will never have to register, log in, or doing any authentic check again, all you need is a credit card.

For those who worry about the security of online shopping, this laptop will actually give them a trustful feeling on internet purchase, no hassle on filling in personal data is required, system within can detect the authentic of signature, meanwhile very convenience and easy to do so, just like they way they make daily transactions.

Apart from all the benefits mentioned above, our clutch bag laptop processed a very fashionable look, dual touch screens wrapped up by leather finishing, clutch bag like, extremely handy and compact, with a clear compartment on surface for keeping little accessories, a totally fresh and cool item for 2013!

#### **Concept 24 - E Chat by Jin Yi from China**

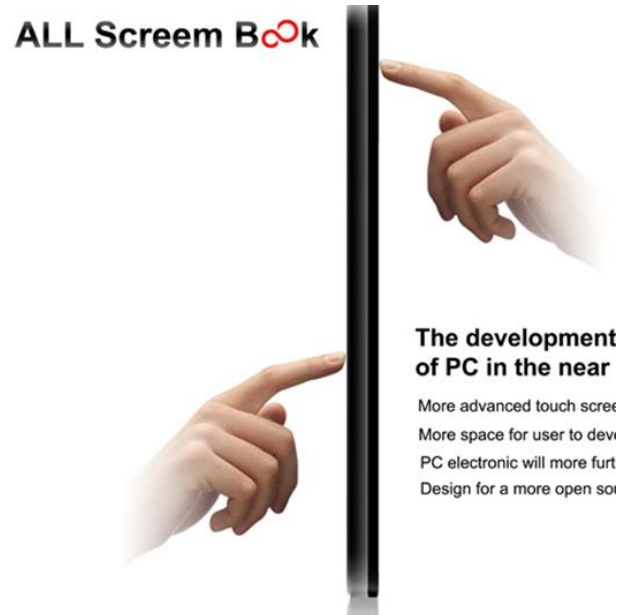


#### **Designer's own words:**

" When the time we had to share space with strangers, such as traveling by train, or drinking coffee on the same table, people always thought it embarrassing to chat with each other. They pretended not to care about each other and kept a distance. Actually many times, people were willing to know new friends if they had some device to send messages for them. Therefore, the LIFEBOOK design targeted for 2013, the near future, is a trying to create a new society between

individuals and people as well as those between people and their computing device via networks. The users can be anyone who eager to communicate with others. And the next-generation laptop will be our life partner to accompany us more time in the day.

**Concept 25** - All screen book by Hao Zhang from China



**Designer's own words:**

" We are living in a continuous electronization world. It is possible for you to see the electronic photo frames, electronic maps, electronic books and digital cameras everywhere. Electronization saves the cost for experiencing so that the further development of electronization seems a must nowadays. In this trend, it is inevitable that the single electronic products will be integrated, which is just the basic concept of All Screen Book. The entire touch screen makes it possible to apply for any electrified products. The outbreak of it is based on the unfixed usages when being produced. You can arrange everything as you like to adjust to your preference, including operating areas, display space, exterior appearance, and so on. For example, you can make the digital camera transform to electronic book by just downloading the related procedures and setting up according to the requirements.

With the development of the technology, various parts of mobile PC is changing profoundly. The screen takes up all the parts without the keyboard finally, which indicates that the current mobile PC makes most of the operating parts become electrified. This means less hardware to be designed, but more choices and usage spaces.

With the development of electronization, it is possible for customers to choose products for many times after purchasing. The customers of All Screen Book can download the themes to change the exterior appearance instead of following the various styles of the manufactures of facing the same products without any changes. What's more, users can even arrange the positions and styles of the buttons by themselves. The less styles designed by manufactures, the more choices for users.

The wireless technology will make enormous progress in the near future. The design of All Screen Book does not have external device interface, both charging and transmission achieve unwiring.

The front display panel of All Screen Book can use various kinds of electronic product interfaces. The development of the software will be more rich in the future. After downloading the needed procedures, you can get the different electronic functions to use anywhere and any time. At the same time, it can develop your PC to the most.

Electronic frame: It is possible to transform to electronic frame mode under the holding state.

Electronic book: The development of the display technique will make the display mode transform to common LED display mode of the electronic book.

Electronic button: It can remote control other multimedia equipments.

# Appendix B – Supporting Materials for Sub-system 1

## Appendix B.1 – Inference Engine

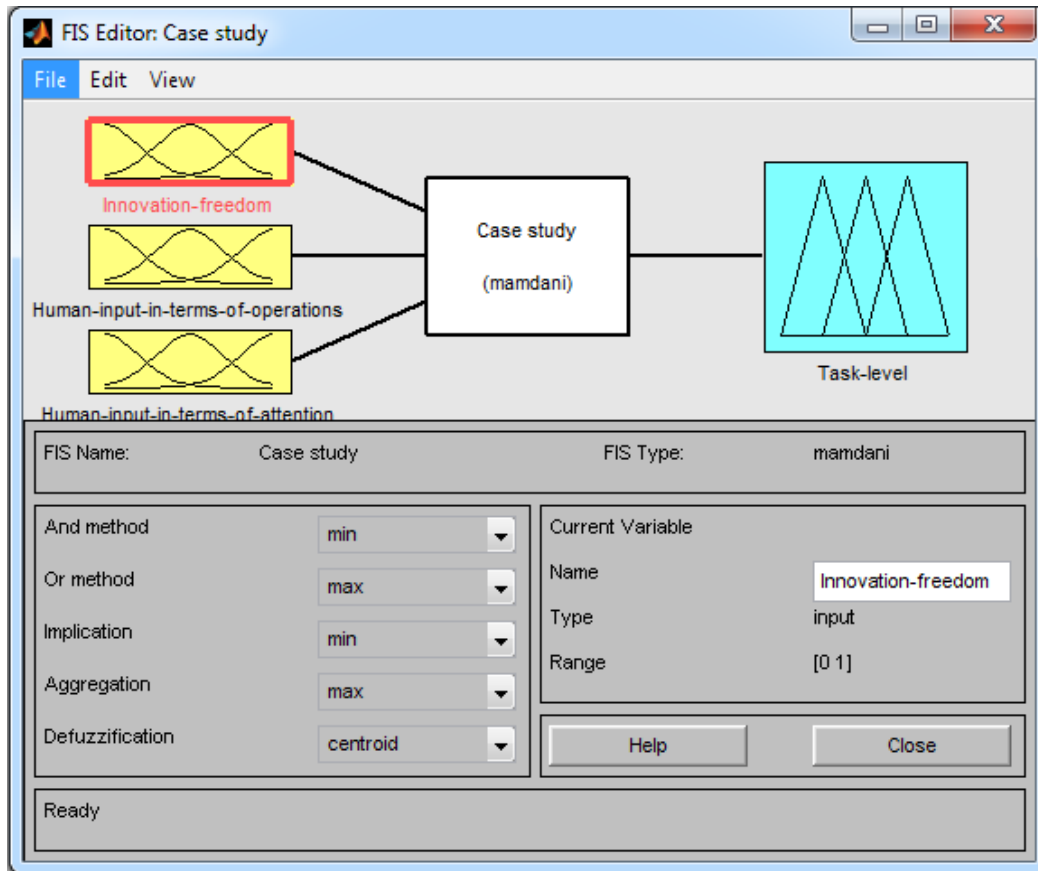


Figure B.1 Inference Engine

## Appendix B.2 – Fuzzy Rules

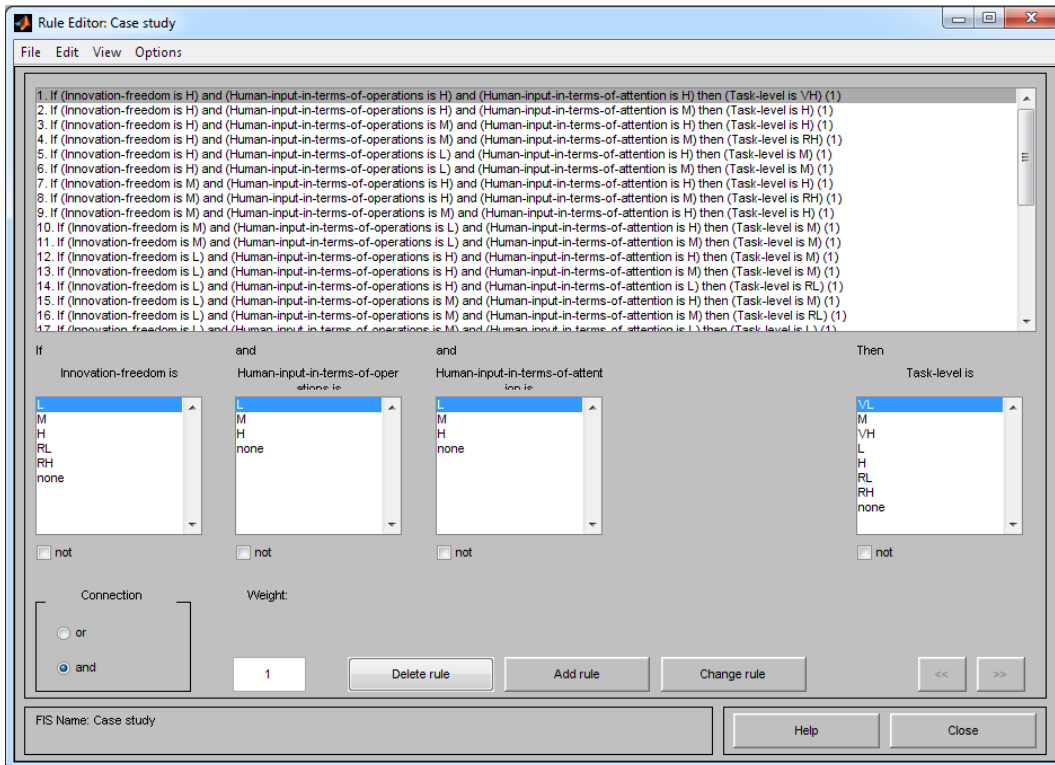


Figure B.2 Fuzzy Rules 1~17

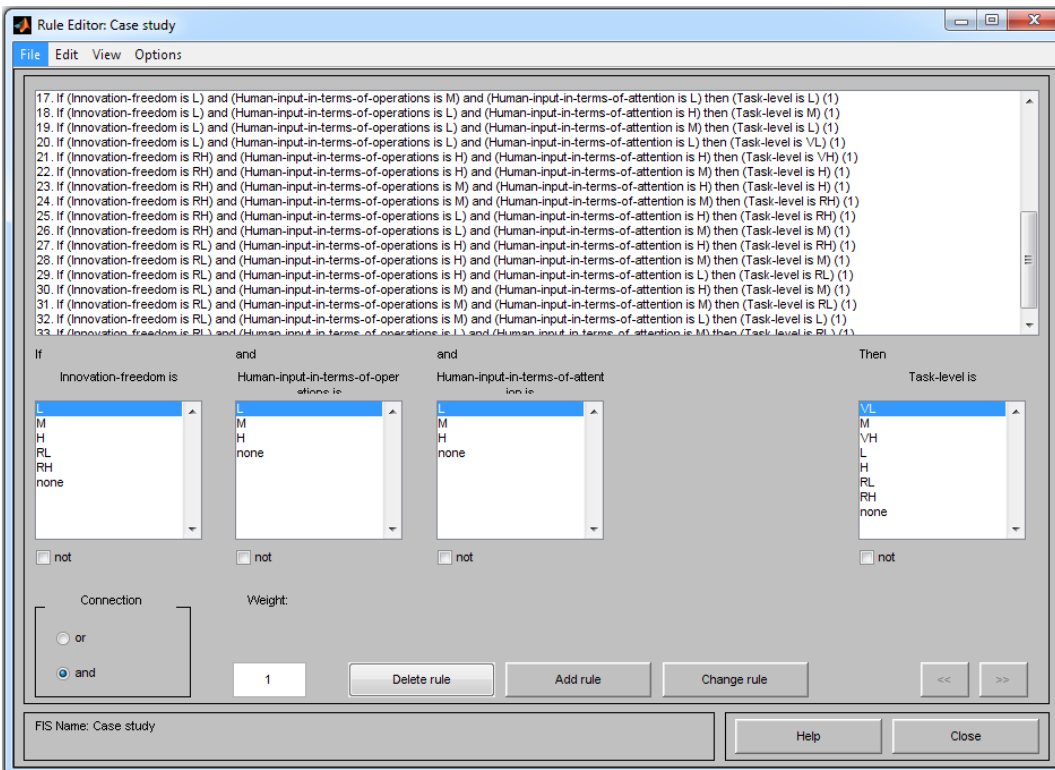


Figure B.3 Fuzzy Rules 18~34

## Appendix C – Supporting Materials for Sub-system 2

### Appendix C.1 – Evaluation results

Table C.1 Evaluation of all concepts

Concept	Human-centered								Novelty								Feasibility								Reliability							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1	4	4	3	4	4	4	3	4	3	3	3	3	4	4	4	3	5	4	3	3	5	5	4	4	3	5	2	3	5	4	4	5
2	5	3	4	4	5	3	2	3	5	5	5	4	5	5	5	5	3	2	1	3	1	2	2	2	3	2	1	3	2	2	3	4
3	4	3	4	4	2	4	3	5	2	2	3	5	2	2	3	1	5	4	5	3	4	2	4	4	3	3	4	4	4	3	4	4
4	2	3	3	4	5	2	3	2	4	4	3	4	5	5	4	2	3	4	3	4	2	2	2	1	3	2	3	3	2	2	2	4
5	3	4	4	3	2	4	3	5	4	2	4	2	3	4	3	2	4	5	4	4	5	4	3	5	3	3	4	3	4	4	3	4
6	4	4	5	4	4	4	4	5	5	3	4	4	2	3	4	5	4	3	4	5	5	3	3	5	5	4	4	4	4	3	4	3
7	2	4	4	3	4	3	3	3	4	2	2	2	2	3	4	2	1	4	4	3	5	3	2	5	2	5	4	2	5	3	2	5
8	3	4	2	2	3	2	3	4	2	2	2	1	2	3	2	1	4	4	4	4	5	4	3	4	5	5	3	3	4	3	3	2
9	4	3	5	3	2	3	3	3	4	4	4	4	4	4	3	4	5	3	4	3	4	3	2	4	4	2	5	2	4	4	3	4
10	2	3	2	3	4	3	3	3	4	2	2	3	5	2	4	3	3	4	3	4	2	2	2	4	2	4	3	2	2	3	2	2
11	2	3	4	4	5	4	3	4	2	2	4	4	3	4	2	4	4	5	5	4	5	3	3	4	3	5	5	4	5	3	3	3
12	4	4	2	3	3	3	3	2	3	5	3	1	4	5	4	4	4	4	4	3	3	3	2	3	4	2	3	2	2	3	2	4
13	2	3	2	3	3	3	3	2	2	3	2	2	5	4	3	2	4	4	4	2	4	3	4	4	3	3	3	3	3	3	4	3
14	2	3	4	4	4	4	4	2	4	5	5	3	2	4	4	5	4	2	4	2	2	3	2	1	2	2	3	2	2	3	2	4
15	2	2	4	4	3	3	3	3	2	3	3	2	2	3	4	2	4	3	4	4	4	4	3	3	4	3	4	3	3	3	3	3
16	2	4	3	3	4	5	4	4	2	3	1	2	4	4	3	2	4	4	4	2	4	4	2	4	3	3	3	3	4	3	2	4
17	2	4	3	4	4	4	3	3	3	4	1	2	2	4	3	1	4	3	5	4	4	4	2	4	4	2	4	2	2	4	2	3
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21	2	3	4	2	3	3	4	5	2	3	2	2	5	4	4	4	4	3	3	3	4	3	2	4	3	2	2	3	2	3	4	3
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23	2	4	3	4	4	4	5	5	3	3	2	2	4	3	2	4	4	4	3	3	4	2	4	4	2	3	3	3	4	2	4	3
24	2	3	2	4	4	4	2	3	2	3	2	2	3	3	2	2	4	4	3	2	3	3	3	5	3	3	3	2	2	3	1	5
25	3	4	3	3	4	4	3	4	2	4	2	2	4	4	4	5	3	3	3	3	4	3	4	5	2	2	3	3	4	3	2	4

Table C.2 Ranking of cluster centroid concepts

Cluster Centroids Ranking Evaluators	Concept 2	Concept 8	Concept 9	Concept 14	Concept 16	Concept 25
	1	1	3	2	6	4
2	1	6	2	3	4	5
3	1	4	2	3	6	5
4	1	6	2	4	3	5
5	3	5	2	6	4	1
6	4	5	3	2	1	6
7	1	3	2	5	4	6
8	6	3	1	5	4	2

Table C.3 Evaluation of better concepts selected by the proposed method and by conventional way

Criteria Concept	Human-centered				Novelty				Feasibility				Reliability			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Evaluator																
Concept 1	4	4	4	3	3	3	4	3.5	5	4	4	3.5	3	5	4	3.5
Concept 3	3.5	4	3	4	2	4	2	2	4.5	4	3	4	3	4	3.5	4
Concept 4	3	3	4	2	4	3.5	5	3	3.5	3	2	2	2.5	3	2	3
Concept 5	4	3	3	4	3	3	3	3	4	4	5	4	3	3	4	4
Concept 6	3	3	4	3	3	2	2.5	3	2	3.5	4	4	4	3	4	3
Concept 7	4	4	4	5	4	4	2	5	3	5	4	4	4	4	3.5	4
Concept 9	4	4	2	3	4	4	4	3.5	4	4	3	3	3	3	4	4
Concept 11	2	3	3	2.5	3	2	3	4	4	3	3.5	4	3	3	3	3.5
Concept 13	2	4	4.5	4	2	4	3.5	3	5	4	4	3.5	4	4.5	4	3
Concept 18	4	4	3.5	3	3	5	4	4	3	4	3.5	3	3	4	4	2

## Appendix C.2 – Extended analysis of the domain-ontology-based concept clustering method

There are several measures to evaluate clustering quality, such as *purity*, *normalized mutual information*, *rand index*, etc. Among these measures, *purity* is a simple and transparent evaluation manner (Manning et al., 2008) and applied in this experiment. To compute *purity*, a standard classification of these concepts should be given so as to provide evidence to estimate the clustering accuracy. For this purpose, a set of concept classes is generated. In particular, the number of classes is set the same with the cluster number  $k$ . Each cluster is assigned to the class which is most frequent in the cluster, and then the accuracy of this assignment is measured by computing the number of correctly assigned documents and diving by total number of documents. The formula is shown below:

$$purity(\Omega, C) = \frac{1}{N} \sum_{i,j=1}^K \max |w_i \cap c_j|$$

where  $\Omega = \{w_1, w_2, \dots, w_K\}$  is the set of clusters, and  $C = \{c_1, c_2, \dots, c_K\}$  is the set of classes;  $w_i$  is the set of documents in  $w_i$ , and  $c_j$  is the set of documents in  $c_j$ .

Concept clustering is performed using both 1) the standard  $k$ -means text/document clustering (SKTC) with common cosine distance measurement; and 2) the proposed CDH-and-Ontology-based  $k$ -means clustering method (CDHOC). In order to take into account the possible influence caused by  $k$ , different  $k$  values are tested to show the clustering effects under varying cluster numbers. Particularly,  $k$  is set as 3, 4, 5, and 6.

### i) Set $k=3$

a) The standard  $k$ -means text/document clustering (SKTC) with cosine distance measurement

**Table C.4** Clustering results using SKTC ( $k=3$ )

Cluster	Concepts
<b>Cluster 1</b>	Concept 2; Concept 3; Concept 5; Concept 8; Concept 9; Concept 13; Concept 15; Concept 21; Concept 22; Concept 25
<b>Cluster 2</b>	Concept 1; Concept 4; Concept 6; Concept 7; Concept 12; Concept 16; Concept 18; Concept 19; Concept 23
<b>Cluster 3</b>	Concept 10; Concept 11; Concept 14; Concept 17; Concept 20; Concept 24

b) The proposed CDH-and-Ontology-based k-means clustering method (CDHOC)

**Table C.5** Clustering results using CDHOC (k=3)

<b>Cluster</b>	<b>Concepts</b>
<b>Cluster 1</b>	Concept 2; Concept 5; Concept 10; Concept 11; Concept 14; Concept 17; Concept 20; Concept 24
<b>Cluster 2</b>	Concept 1; Concept 3; Concept 4; Concept 7; Concept 9; Concept 13; Concept 15; Concept 18; Concept 22
<b>Cluster 3</b>	Concept 6; Concept 8; Concept 12; Concept 16; Concept 19; Concept 21; Concept 23; Concept 25

ii) Set k=4

a) The standard k-means text/document clustering with cosine distance measurement

**Table C.6** Clustering results using SKTC (k=4)

<b>Cluster</b>	<b>Concepts</b>
<b>Cluster 1</b>	Concept 1; Concept 4; Concept 9; Concept 15; Concept 19; Concept 21; Concept 25
<b>Cluster 2</b>	Concept 2; Concept 3; Concept 5; Concept 7; Concept 13
<b>Cluster 3</b>	Concept 6; Concept 8; Concept 12; Concept 16; Concept 18; Concept 22; Concept 23
<b>Cluster 4</b>	Concept 10; Concept 11; Concept 14; Concept 17; Concept 20; Concept 24

b) The proposed CDH-and-Ontology-based k-means clustering method

**Table C.7** Clustering results using CDHOC (k=4)

<b>Cluster</b>	<b>Concepts</b>
<b>Cluster 1</b>	Concept 2; Concept 5; Concept 10; Concept 11; Concept 14; Concept 17; Concept 20; Concept 24
<b>Cluster 2</b>	Concept 6; Concept 8; Concept 15; Concept 19; Concept 21; Concept 22; Concept 23; Concept 25
<b>Cluster 3</b>	Concept 12; Concept 16
<b>Cluster 4</b>	Concept 1; Concept 3; Concept 4; Concept 7; Concept 9; Concept 13; Concept 18

### iii) Set k=5

a) The standard k-means text/document clustering with cosine distance measurement

Table C.8 Clustering results using SKTC (k=5)

Cluster	Concepts
Cluster 1	Concept 1; Concept 9; Concept 15; Concept 21; Concept 25
Cluster 2	Concept 4; Concept 6; Concept 18; Concept 19
Cluster 3	Concept 2; Concept 3; Concept 5; Concept 7; Concept 13;
Cluster 4	Concept 8; Concept 12; Concept 16; Concept 22; Concept 23
Cluster 5	Concept 10; Concept 11; Concept 14; Concept 17; Concept 20; Concept 24

b) The proposed CDH-and-Ontology-based k-means clustering method

Table C.9 Clustering results using CDHOC (k=5)

Cluster	Concepts
Cluster 1	Concept 8; Concept 15; Concept 21; Concept 22
Cluster 2	Concept 12; Concept 16
Cluster 3	Concept 1; Concept 3; Concept 4; Concept 7; Concept 9; Concept 13; Concept 18
Cluster 4	Concept 2; Concept 5; Concept 10; Concept 11; Concept 14; Concept 17; Concept 20; Concept 24
Cluster 5	Concept 6; Concept 19; Concept 23; Concept 25

### iv) Set k=6

a) The standard k-means text/document clustering with cosine distance measurement

Table C.10 Clustering results using SKTC (k=6)

Cluster	Concepts
Cluster 1	Concept 1; Concept 9; Concept 15; Concept 25
Cluster 2	Concept 2; Concept 3; Concept 13; Concept 21
Cluster 3	Concept 4; Concept 6; Concept 18; Concept 19
Cluster 4	Concept 5; Concept 7
Cluster 5	Concept 8; Concept 12; Concept 16; Concept 22 ; Concept 23
Cluster 6	Concept 10; Concept 11; Concept 14; Concept 17; Concept 20; Concept 24

b) The proposed CDH-and-Ontology-based k-means clustering method

Table C.11 Clustering results using CDHOC (k=6)

Cluster	Concepts
Cluster 1	Concept 12; Concept 16
Cluster 2	Concept 1; Concept 3; Concept 4; Concept 7; Concept 9; Concept 13; Concept 18
Cluster 3	Concept 10; Concept 11; Concept 14; Concept 17; Concept 20 ; Concept 24
Cluster 4	Concept 6; Concept 19; Concept 23; Concept 25
Cluster 5	Concept 8; Concept 15; Concept 21; Concept 22
Cluster 6	Concept 2; Concept 5

The *purities* of SKTC and CDHOC are obtained as in [Table C.12](#). Overall, the clustering effect of the proposed CDHOC is better, especially when  $k$  increases, CDHOC show more advantages in achieving more accurate clustering results. Therefore, it appears that the proposed method would be helpful to reach better clustering results.

Table C.12 Overall clustering effects of SKTC and CDHOC

K	Purity (SKTC)	Purity (CDHOC)	Evaluation result (better result is from)
3	$(1/25) \times (5+5+2) = 0.48$	$(1/25) \times (4+4+3) = 0.44$	SKTC
4	$(1/25) \times (3+1+4+2) = 0.4$	$(1/25) \times (3+0+4+3) = 0.4$	SKTC= CDHOC
5	$(1/25) \times (2+1+2+2+2) = 0.36$	$(1/25) \times (3+1+3+1+2) = 0.4$	CDHOC
6	$(1/25) \times (1+2+1+1+2+1) = 0.32$	$(1/25) \times (0+2+1+2+2+2) = 0.36$	CDHOC

## Appendix D – Supporting Materials for Sub-system 3

### Appendix D.1 – A summary of existing definitions related to innovativeness

Reference	Definition
	<i>General definition (radical, really new, discontinuous, architectural, evolutionary, revolutionary, highly innovative, major, break-through, and substantial)</i>
de Brentani, 1989	The degree to which any new product or feature also has functional relevance to its potential user group
Olson et al., 1995	The degree to which you disagree or agree with the following statements: High quality technical innovations were introduced during the development of this product. Compared to similar products developed by our competitors, our product will offer unique features/attributes/benefits to the customers. Our product introduces many completely new features to this class of products. Compared to similar products developed by our organization, our product will offer unique features/attributes.
Firth & Narayanan, 1996	Classical notion of innovativeness defined in terms of the relative difference between new and previous offerings still remains at the core of product innovativeness definitions
Garcia and Calatone 2002	Innovativeness refers to the degree of “newness” of an innovation, whether newness to the world, to the industry/market, or to the firm
Hauschildt 2004, p. 14	The degree of novelty of an innovation (or synonymously: product innovativeness) expresses the degree of difference of an innovation in relation to the previous state
Augusto and Ceolho 2009	The degree of a product’s newness
Bao, Sheng and Zhou 2012	The degree to which a new product offers novel attributes or unique benefits to the market
	<i>Consumer innovativeness is considered to be the openness of information processing</i>
Rogers and Shoemaker 1971	Consumer innovativeness (behavioral perspective): "the degree to which an individual adopts innovations relatively earlier than other members in his or her social system"
Goldsmith 1984; Leavitt and Walton 1975	An individual's receptivity to new experiences and novel stimuli
Hurt, Joseph, and Cook 1977	Generalized personality trait reflecting "a willingness to change."
Midgley and Dowling 1978	The concept of innovativeness involves communication independence, determined by the degree to which a consumer's decision process is independent of others' personal influence in the social system
Goldsmith and Hofacker 1991, p. 211	Consumer innovativeness is defined as “the tendency to learn about and adopt innovations (new products) within a specific

	domain of interest.”
Hirschman 1980 and Manning et al. 1995	Consumer novelty seeking, which is defined as an inherent desire to seek out novelty and creativity.
Midgley and Dowling 1993	Innovative predisposition: generalized unobservable predisposition toward innovations applicable across product classes
Steenkamp, ter Hofstede, and Wedel 1999	The predisposition to buy new and different products and brands rather than remain with previous choices and consumption patterns
<i>Innovativeness of new consumer products</i>	
Amabile 1983; Jackson and Messick 1965	Novel and appropriate; Novelty refers to the extent to which a concept, idea or object differs from conventional practice within the domain of interest; Appropriateness is the extent to which a given out-put is viewed as useful or beneficial to some audience
Andrews and Smith 1996	Meaning novelty in the context of marketing programs for mature products
Sethi, Smith and Park 2001	The notion of “meaning uniqueness” provides the foundation for the definition of new product innovativeness; conditions for creativity, diversity of input, discovery of novel linkages, motivation to innovate, challenging traditional perspectives, promoting risk taking, resource availability
<i>Behavioral-level innovativeness</i>	
Jackson 1976	The global trait view argues that innovativeness is a type of personality trait.
Foxall, 1993, 1994	The degree of innovativeness they possess depends on how quickly they adopt after encountering the innovation
Popkins, 1998	Openness to experience: how willing people are to make adjustments in notions and activities in accordance with new ideas or situations
Goldsmith and Foxall 2003	Innovativeness refers to interindividual differences in how people react to these new things and accounts for much of their success or failure
<i>Organization-level innovativeness</i>	
Wang and Ahmed, 2004; Hurley and Hult, 1998	The firm innovativeness is a multidimensional construct involving several aspects such as product, process, market, technological and strategic planning
Wang and Ahmed, 2004	Product innovativeness refers to the novelty and meaningfulness of new products introduced to the market in a timely fashion
Garcia and Calantone 2002; Gumusluoglu and Ilsev 2009; Luo and Bhattacharya 2006	Program innovativeness, which refers to a company’s ability to generate a range of goods or services that are new and meaningful to customers and that differ from existing alternatives
Auh & Menguc, 2005:250	Firm innovativeness can be seen as an organization's inclination to “engage in innovative behavior”

Molina-Castillo, Jimenez-Jimenez and Munuera-Aleman, 2011	Innovativeness to the firm: Developing this product was a technologically complex affair; The development process was complicated; The new product developed was complex.
Augusto & Coelho, 2009	Innovativeness to the firm that is characterized by radical change, risk and experimentation and that allows for the creation of new methods, relationships, products or services
Danneels and Kleinschmidt, 2001	Within the firm's perspective, environmental familiarity and project-firm fit, and technological and marketing aspects are proposed as dimensions of product innovativeness
<i>Multi-dimension constructive definition</i>	
Salomo (2003, p. 412 et seq.); Billing (2003, p. 30 et seq.)	Product innovativeness can be conceptualized with the help of the following four dimensions: degree of technological innovation; degree of organizational innovation; degree of environmental innovation

## Appendix D.2 – A summary of emotions related to innovation evaluation

	Ekman, 1973	Izard, 1977	Plutchik, 1980	Tomkins, 1984	Epstein, 1984	Shaver et al., 1987	Frijda et al., 1995	Oatley & Johnson-Laird, 1987
Negative	Fear	Fear	Fear	Fear	Fear	Fear	Fear	Fear
	Anger	Anger	Anger	Anger	Anger	Anger	Anger	Anger
	Sadness	Distress	Sadness	Distress	Sadness	Sadness	Sadness	Sadness
	Disgust	Disgust	Disgust	Disgust	-	-	-	Disgust
	-	Contempt	-	Contempt	-	-	-	-
	-	Shame	-	Shame	-	-	-	-
-	Guilt	-	-	-	-	-	-	
Positive or negative	Surprise	Surprise	Surprise	Surprise	-	Surprise	-	-
Positive	Happiness	Joy	Joy	Joy	Joy	Joy	Happiness / Joy	Happiness
	-	-	Acceptance	-	Love	Love	Love	-
	-	Interest	-	Interest	-	-	-	-
	-	-	Anticipation	-	-	-	-	-

Figure D.1 Basic Emotions (Refer to Desmet 2012)

Emotion type	Emotion words
<i>Desmet 2012</i>	
Admiration	Admiration, impressed, esteem
Amusement	Amused, entertained, gaiety, merry, playful, humorous, glee, funny, laughing, jolly

Anticipation	Anticipation, eager, expectant
Confidence	Confident, assurance, secure, trust
Courage	Courageous, brave, heartened
Desire	Desire, attracted, ardent, longing, craving, yearning, nostalgic
Dreaminess	Dreamy, contemplative, pensive
Enchantment	Enchanted, awe, charmed, moved, touched, enthrallment, wonder
Energized	Energetic, exuberant, zest, active, excited, stimulated
Euphoria	Euphoric, rapture, ecstasy, exaltation, thrilled, elated, high, exhilaration, exultation, jubilant, enraptured
Fascination	Fascinated, interest, curious, inquisitive, attentive, engrossed
Hope	Hope, optimistic, encouraged, wishful
Inspiration	Inspiration, enthusiasm, tempted, determined, challenged, zeal
Joy	Joy, bliss, overjoyed, pleasure, happy, good, delighted, wonderful, rejoice, smile, cheerful, enjoyment
Kindness	Kind, caring, friendly, tenderness, warm
Love	Love, romantic, infatuation, sentimental, fondness, in love, liking, affection, intimate
Lust	Lust, horny, passion, aroused, sensual, sexy
Pride	Pride, triumphant, self-satisfaction, smug
Relaxation	Relaxed, at peace, at ease, comfortable, peaceful, lighthearted, carefree, placid, serene, tranquil, easygoing, calm
Relief	Relief, reassured, gratitude, soothed, thankful
Respect	Respect, appreciating, approve
Satisfaction	Satisfaction, gratified, pleased, contentment, fulfilled, glad
Surprise	Surprise, amazement, astonished, startled, dazzled
Sympathy	Sympathy, compassion, empathy, pity, understanding, forgiving
Worship	Worship, adoration, devotion, reverence
<i>Desmet, Porcelijn and van Dijk, 2007</i>	
Pleasant surprise	Suddenness, unexpectedness
Fascination	Pleasant sense of unfamiliarity, curiosity
Desire	Possession, delightful
<i>Na and Suk, 2014</i>	
Charming; Calm/graceful/mild; Cheerful; Classic; Clean/clear; Comfortable ; Dignified/elegant/noble; Cozy/soft; Delicate; Cute; Flamboyant; Impressive/stand out; Fresh; Light/weighty; Lovely; Luxurious; Modern/sophisticated; Neat; Sensuous; Weak	